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MONTEREY, CALIFORNIA

THESIS

**USING AGENT-BASED MODELING TO ASSESS THE IMPACT
OF MARTIAL LAW ON A REPRESENTATIVE IRAQI TOWN**

by

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December 2004

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LAW ON A REPRESENTATIVE IRAQI TOWN**

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ABSTRACT

One of the main challenges in the modeling and simulation community today is the study of human behavioral aspects, which are often not key considerations in traditional combat-oriented attrition-based models.

In a martial law scenario, military or peacekeeping forces may be put in place to restore law and order and conduct a wide range of operations, such as setting up road blocks, imposing curfew, distributing food and manning checkpoints. This thesis focuses on the checkpoint operation and uses the agent-based modeling software PAX to assess the impacts of such a scenario on the population.

Results indicate that civilians' level of anger and fear, needs and soldiers' rules of engagement play important roles in determining the success of peace support operations.

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The reader is hereby cautioned that the computer programs and scenario files mentioned herein are developed solely for the purpose of this thesis research. While every practical effort has been made, within the time and resources available, to ensure that the programs and scenario files are free of computational and logic errors, they may not be considered validated in any ways. Any application of these programs and scenario files without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

Due to the complexity and dynamism of human emotions, traditional combat-oriented attrition-based models often do not sufficiently model the human behavioral aspects such as fear, anger and needs. In a martial law scenario, military or peacekeeping forces may be put in place to restore law and order and conduct operations ranging from setting up road blocks to imposing curfew, distributing food and manning checkpoints.

Previous attempts to model some of these scenarios, such as food distribution, have shown positive results as well as limitations to current simulation approaches. The evolvement of agent-based simulation and maturing of data-farming techniques allow a more detailed look at some of these peacekeeping scenarios.

This thesis focuses on the modeling of the checkpoint operation and uses the agent-based modeling software PAX to assess the impacts of such a scenario on the population. Through the use of linear regression techniques, simple models are developed that can highlight some of the key factors that are critical to the success of peace support operations.

In the presence of a disturber group, the initial anger and readiness for aggression play an important role in determining the escalation levels of the situation. This implies that if crowds are allowed to loiter and gather, the risk of conflict increases when opposing groups interact. It is also more difficult to disperse a rowdy crowd than to prevent the crowd from forming in the first place. In terms of rules of engagement, when the soldiers employ the Gandhi strategy of always pacifying, it surprisingly leads to high escalation. The civilians simply take advantage of the soldiers' limited actions, and as a result, the situation explodes to high escalation. However, the overall fear level of the civilians is somewhat controlled with pacifying tactics. Fear level is also affected by the initial need or motivation of the civilians to achieve their goals of going across the checkpoint or the need for food. With a high need, they tend to be more focused

on fulfilling their need and they are less likely to engage in violence. Therefore, some tactics may be more suitable than others in different situations. On one hand, the decision maker would like to contain the escalation, but at the same time without the need to resort to hard-handed tactics to keep the crowd under control. There is a need for the decision maker to juggle between these conflicting requirements and what trade-offs might be necessary.

The results in this thesis represent an initial step towards understanding how rules of engagement can be used to better achieve short-term and long-term objectives in operating a checkpoint. Further work is necessary. Some of these require more sophisticated models. For example, the effects of the presence of a civilian leader could not be fully established since PAX currently models the cooperation of the leader with the soldiers only. The civilians' cooperation with their leaders, as well as cooperation with the soldiers, are also factors worth exploring. If MOEs were recorded separately for the different civilian groups (such as those allowed to pass through the checkpoint, and those restricted from passing), then each group could be investigated separately and this might provide more insight into the crowd behavior. Currently soldiers patrolling on foot could not be modeled in PAX. Adding patrol capabilities seems important, since our findings suggest escalation is lower when angry crowds can be prevented from forming near the checkpoint. It would certainly improve the modeling fidelity in a checkpoint or curfew scenario.

Overall, the use of PAX in this research has established positive results in investigating the human behavioral aspects in simulation, thus paving the road ahead for future agent-based modeling research.

I. INTRODUCTION

A. BACKGROUND

Over the last two decades, armed conflicts between conventional forces fighting in a stereotypical war zone have become a thing of the past. General Charles Krulak, the former U.S. Marine Corps Commandant between 1995-1999 who first coined the term a “three-block-war” has said that today’s troops are going to find themselves engaged in operations ranging from humanitarian missions, through peace keeping actions, to fighting a full-blown combat, all possibly within the space of three city blocks [Burgess, 2003].

Efforts to better understand Military Operations in Urban Terrain (MOUT) and Military Operations Other Than War (MOOTW) have begun, and the Modeling and Simulation (M&S) community has also recognized the need for further research to gain insights into the complexities of such operations. Specific focus areas include, but are not limited to, the study of human behavioral patterns, the effects of group dynamics and population interactions (coupled with the cultural, ethnic, religious and racial backgrounds), and the impact of psychological influence on the various types of missions.

Iyad Allawi, the Iraqi prime minister who heads the interim government put in place on 28 June 2004, has hinted at the possibility of instituting martial law to cope with security issues. President Bush has said that the coalition forces in Iraq would support such a possible decision to deal with escalating violence and terror attacks. However, the Iraqi military has suffered greatly as a result of the war. Can the Iraqi military then take effective actions and measures against criminals, such as imposing curfew, manning road blocks and checkpoints, performing cordon and search missions to weed out the criminals, or distributing food to the needy population?

B. PURPOSE

The purpose of this thesis is to develop a scenario to gain insight and better understanding of the critical factors that might affect the outcome of peacekeeping operations in a representative Iraqi town. It is not intended to be used for prediction. Furthermore, by pointing out the pros and cons of this model, it helps to provide some feedback to the software developers that can be taken into consideration for future improvement to the modeling platforms. The results may suggest interesting new questions that we would not have otherwise thought of, but could be explored using agent-based models.

C. SCOPE

Given that the situations are so dynamic and that war is so complex, a vast number of scenarios could develop. This research focuses primarily on the impacts of instituting martial law in a representative Iraqi town, particularly the execution of a checkpoint scenario. Initial efforts entail reviewing existing agent-based simulations that would possibly provide initial experimental setups. We build a model abstraction of a representative Iraqi town in the simulation that reflects the general environmental layout, the population, and the affinity towards U.S. and coalition troops.

Simulations are conducted using PAX, an agent-based modeling software package. Data collected is analyzed with statistical tools. Simple linear regression models are built and critical factors are identified for the decision makers to consider.

D. RESEARCH QUESTIONS

With the model abstraction of the town, population and various scenarios built, this thesis seeks to investigate the critical factors that could possibly affect the outcomes of the peace support operations.

Some of the research questions include, but are not limited to:

- Does the size and composition of U.S. and coalition forces matters in the proper manning of checkpoints?
- What effects do certain Rules of Engagement (ROE) imposed on soldiers have on crowd control and management?
- How would group dynamics and presence of leader affect the crowd's behavior?
- Are hungry and needy people more prone to violence?

E. INTRODUCTION TO AGENT-BASED MODELING

Interests in using agent-based modeling for combat date back to as early as 1995 with the development of a model called Irreducible Semi-Autonomous Adaptive Combat (ISAAC), which was a proof-of-concept model to illustrate how combat may be viewed as emergent self-organized dynamical process involving complex adaptive agents interacting and co-evolving [Ilachinski, 1997]. Efforts were put into improving and adding capabilities to the model and it was subsequently developed into Enhanced ISAAC Neural Simulation Tool (EINSTEIN) [Ilachinski, 1997].

Agents are basic entities that behave autonomously, making their own decisions in action, movement or communications, governed only by simple rules. They interact with other agents and the environment, often producing behaviors that are not obvious from the basic rules and could possibly evolve as a result of group dynamics.

Simplicity remains one key principle to agent-based simulations. They should be easy and quick to set up and usually run very fast. This allows analysts to vary the parameters over a wide range of values and do experiments with multiple runs in short periods of time.

F. INTRODUCTION TO PROJECT ALBERT

In 1998, Project Albert was chartered by Congress to address needs of military decision makers traditionally not supported by conventional methods. The project's vision includes strong inter-disciplinary collaborative teams to include joint (Marine Corps, other services and DoD agencies) and coalition partners (Germany, Sweden, Australia, New Zealand and Singapore) to attempt to address previously unanswered questions relevant to success in modern warfare [Project Albert Factsheet, 2002].

Within the Project Albert community, the (agent-based) computer models are often referred to as “distillations”. Ideally, a distillation model has the following characteristics: transparency, speed, ease of configurability to the question at hand, and requirement of little training to use [Horne, 2001]. There are other types of models used to examine combat scenarios. Table 1 illustrates some of the pros and cons of various techniques [Horne, 2001].

	Pros	Cons
Wargames	Provides a common tableau for discussion; enhances mutual understanding; allows the imagination to roam	Non-reproducible; often dominated by personalities; limited options; unrealistic opposition
Equations	Only one “run” needed; appeals to our background; ideal when steady state solutions apply	Validation almost impossible without a theory of war; Sensitivity to initial conditions a problem; Relations may not be functions of usual variables; Binary events a problem; Closed form solutions rare
Simulations	May be only way to get a high fidelity sample; Sample validity difficult but doable; experimental data may contribute	Epimorphism onto space of outcomes problematic; Validation of ensembles beyond current state of art; important variables may not be accessible; binary events are a major challenge
Distillations	Validation often trivial; can handle non-linearities, binary events, sensitivity to initial conditions, emergence; fun; accessible to all; adaptable to massively parallel machines; can create all the data need; can relate to intangibles and coevolving landscapes	Accreditation is a ridiculous issue; sampling possible but may require new statistics; visualization a challenge

Table 1 Pros and cons of various techniques.

By running experiments on distillations that examine a large data space, analysts seek to look into areas that traditional complex, high-fidelity, high-resolution simulations could not or have not explored, with the ultimate goal of developing better maneuver warriors.

G. THESIS ORGANIZATION

This document is organized into five chapters. Chapter I provides the introduction and background to the situation and the purpose of this research work.

In Chapter II, we look at the problem in slightly more detail and attempt to highlight some of the past research efforts in similar areas of interest. Discussions of various measures of effectiveness, otherwise known as MOEs, are also included in this chapter

In Chapter III, we introduce PAX and describe how the model is built using this agent-based software package. This is not intended to teach the readers how to use the software, but to highlight some of the key features. The readers are encouraged to refer to the PAX User's Manual [Schwarz, 2003] for further details.

In Chapter IV, we describe the efficient experimental design used to explore the scenario, and present the results and detailed analysis of the experiment.

Conclusion and recommendations for future work are presented in Chapter V.

II. PROBLEM DEFINITION AND ASSUMPTIONS

A. CHAPTER OVERVIEW

This chapter looks at some of past studies and thesis work and highlights some of the results and lessons learned. Due to the different natures of conventional warfare and peacekeeping operations, traditional yardsticks may not be appropriate to gauge the success of peacekeeping operations and hence an appropriate set of MOEs need to be identified and defined.

B. PROBLEM DEFINITION

Military strategists focus on the objective of winning the war, often neglecting the equally important peace building efforts. In the current Gulf War II, there has been doubt that the coalition forces ever dedicated sufficient time or resources to planning for the occupation in Iraq. The Allies planned for three years to occupy Germany during World War II, while serious planning for the occupation of Iraq was done in a matter of a few months. While the main bulk of the U.S. Central Command planners and experts in Washington focused on planning for the war, far fewer resources went into preparing for peace [Carafano, 2004].

Other than such post-conflict efforts, the United Nations estimates that there are more than 60,000 military and civilian personnel from at least 100 nations currently involved in peacekeeping operations as of 31 July 2004 [United Nations Peacekeeping Operations Background Notes 1, 2004]. Figure 1 shows the missions ongoing at this time, such as United Nations Mission of Support in East Timor (UNMISET) and United Nations Mission in Liberia (UNMIL).

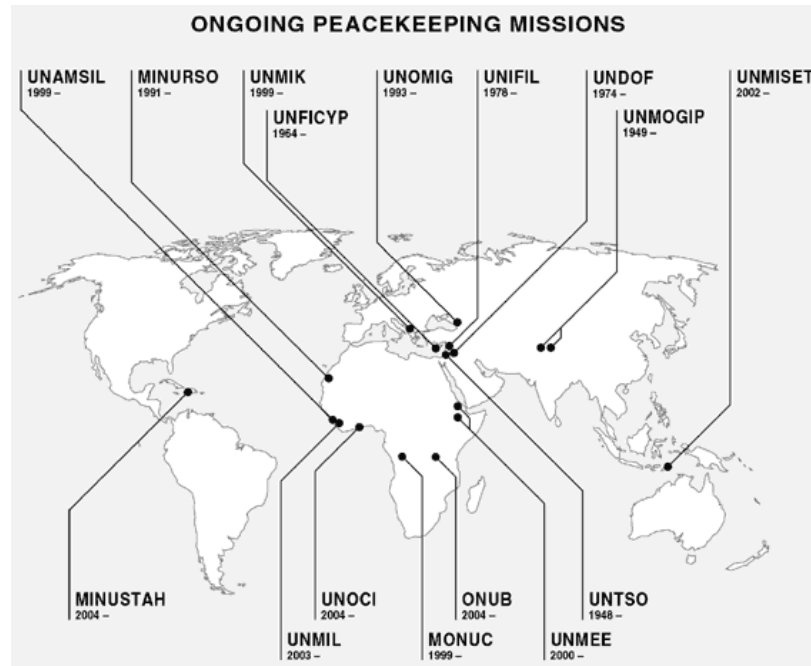


Figure 1 Ongoing Peacekeeping Missions.

C. PAST STUDIES

Due to the complexity and diversity of human behavioral patterns, most traditional simulation and modeling efforts avoided modeling this aspect and instead focused on the attrition-based engagement models. With the development of agent-based modeling platforms such as MANA, Pythagoras, Socrates and PAX, opportunities for investigating some peacekeeping operation scenarios arose. We briefly summarize a few recent studies.

1. Food Distribution Scenario Using MANA

During the 4th Project Albert International Workshop held during the summer of 2001 in Cairns, Queensland, Australia, the Peace Support Operations Working Group focused on a food distribution scenario using the MANA agent-based modeling platform [Bjorkman, 2002]. The scenario described a small peacekeeping force arriving at a village marketplace to hand out food packages to the needy civilians. The hungry civilians were initially friendly to the peacekeeping force, but after receiving food, they could possibly turn aggressive and hostile.

The following are the variations to the scenario used to investigate effects of different force sizes and distribution points.

In the first scenario, the Blue force is organized as one squad of 15 agents distributing food to 60 civilians in one location. In the second scenario, the Blue force is still organized as one squad of 15 agents, but the civilians are divided into 3 groups of 20 each, and placed in 3 different regions. In the final scenario, the Blue force is then split into 3 squads of 5 agents each, carrying food distribution missions to groups of 20 civilians in 3 different locations. Figure 2 shows the different scenario setups [Schwarz, 2003].

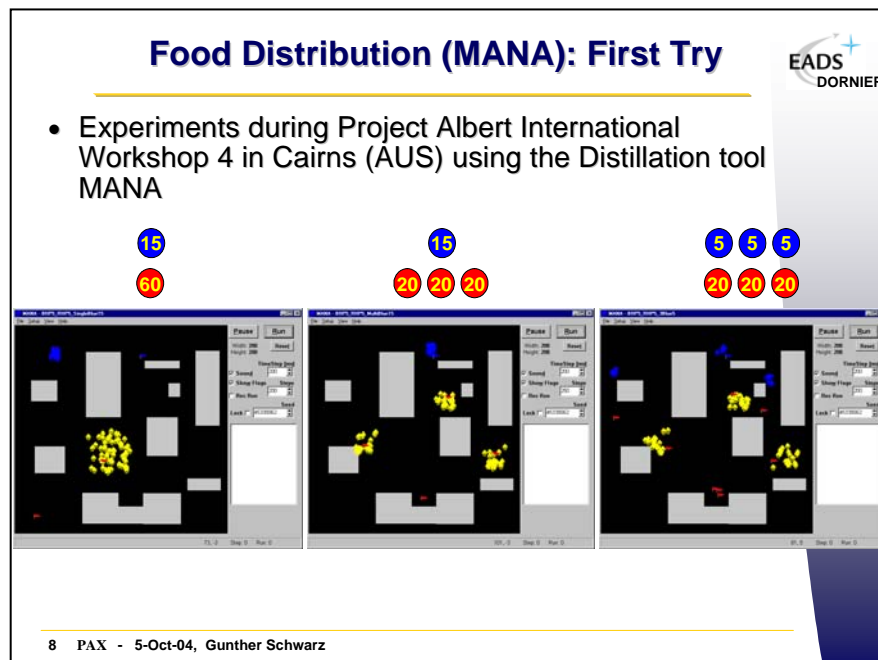


Figure 2 Food Distribution Scenario Setup.

Some of the questions that the Working Group tried to answer are:

- Do single or multiple distribution points matter to the outcome of the situation?
- Do different ways of task organization of the Blue force impact the outcome?

- What size of Blue force and type of equipment are necessary to subdue a situation when needy civilians turn violent?
- What tradeoffs, if any, can be made between equipment and organization to positively influence the outcome?

Figure 3 [Schwarz, 2004] shows Blue and Red (representing civilians) force losses are shown by the bars below and above the x-axis, respectively. The numbers in parentheses below the bars indicate the Loss Exchange Ratios. The exposure time is the length of time that the Blue force requires to conduct the food distribution operation. The two bars for each scenario represent the two exposure times (short and long) used for the runs.

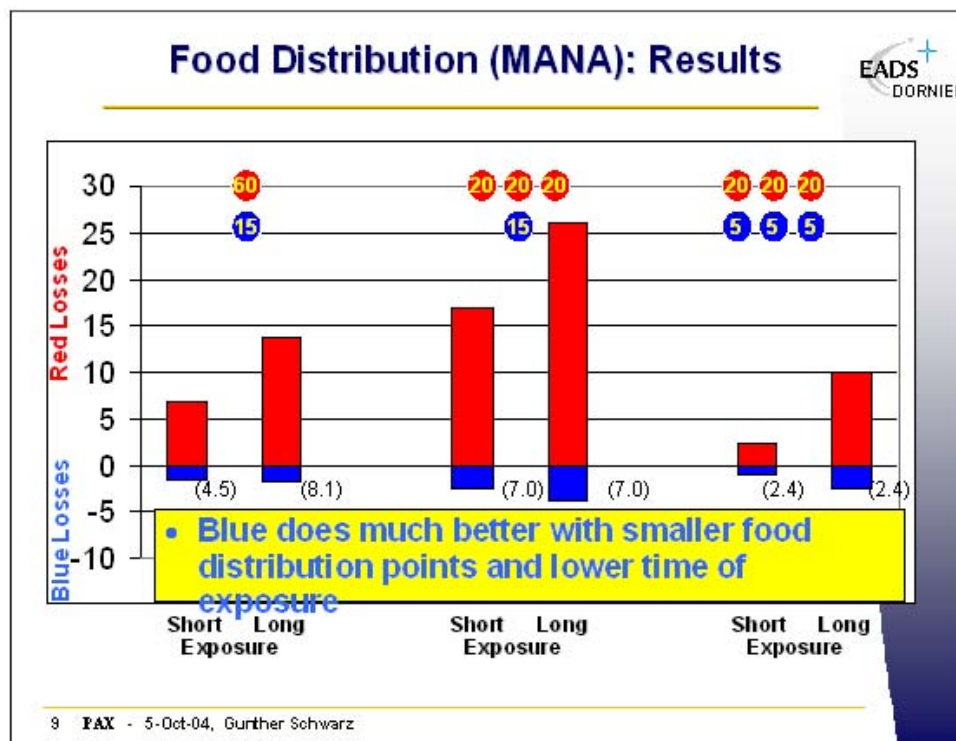


Figure 3 The Results of Three Food Distribution Scenarios.

Note that the worst results occur when one squad of 15 Blue agents tries to distribute food at three different locations. This could be due to the increase in likelihood of confrontation in multiple encounters as well as the bigger squad size

that might have made the civilians felt more threatened. In the case when the Blue force is smaller to deal with similarly smaller crowds, the overall casualties are lowest, along with shorter exposure times.

2. Modeling Logistics Support in an Urban Humanitarian Assistance/Disaster Relief (HA/DR) Environment

The Logistics Working Group of the 6th Project Albert International Workshop investigated a similar food distribution scenario using MANA, but added the aspect of convoy protection [Wolf et al., 2003].

The convoy followed a predefined route to the disaster relief site. There were civilians that, upon seeing or hearing the convoy passing by, would try to follow the trucks. The experiment then investigated how factors such as convoy speed, red aggression and civilians' propensity to go after the convoy affect the number of people that could be fed. Figure 4 shows a screen shot of the MANA graphical user interface, depicting a model abstraction of the town setup.



Figure 4 Protection of Convoy Scenario using MANA.

Blue agents represent a convoy of marines, yellow agents are civilians in need of humanitarian assistance, and a single red agent represents some form of direct harassing fire on the convoy.

The Working Group observed that the slower the convoy moves, the more of an opportunity the civilians have to gain and maintain contact and hence more people could be fed. On the other hand, the aggression of the red agent makes no difference in the number of neutrals fed unless red scores a kill on the blue. It is important that there is enough security to guard against a truck being killed. The study sets the stage for future work which eventually leads to thesis research [Wolf, 2003] and a paper [Wolf et al., 2003] and involving detailed modeling and analysis of humanitarian assistance/disaster relief operations.

3. Experiments with the Model PAX: Investigating Escalation Processes in Peace Support Operations

During the 6th Project Albert International Workshop [Schwarz et al., 2003] held in Monterey, California in March 2003, the Peace Support Operations Working Group looked at the food distribution scenario again using the German-developed agent-based model PAX. The scenario described a small peacekeeping force arriving at a village marketplace to hand out food packages to the needy civilians.

The experiments were conducted with 20 and 50 civilians, all having the same parameter settings at the beginning of each simulation run. Table 2 shows the range of values that were varied to reflect different civilian population groups.

	Min	Max	Default	Interpretation/Explanation
Need	0	100	90	The civilians have a high need for goods.
Anger	0	100	30	There is some anger, which is not too high in the beginning.
Fear	0	100	50	Fear is on a medium level.
Readiness for Aggression	0	100	70	The civilians are quite ready to act violently.
Group Cohesiveness	0	100	10	The feeling of belonging to the surrounding group is on a rather low level.
Norms for Anti-aggression	0	100	10	The civilians are used to living in an aggressive environment.

Table 2 Civilians Base Parameter Settings.

The set of questions of interest to the Working Group include:

- Can escalation be avoided in the examined scenario settings?
- Can the food packages be distributed?
- What kind of peacekeeping course of action (tactic) is adequate in a certain situation?
- How are different MOEs influenced by the soldier's actions?
- How much might long term goals be jeopardized, even if an operation seems to be successful at first sight?

Figure 5 [Schwarz et al., 2003] shows the result of running and animating the scenario in PAX. This allows the user to observe and analyze the whole process. The blue square represents the food distribution site, the blue dots represent the soldiers, and the other dots represent civilians with different levels of need, fear, and anger.

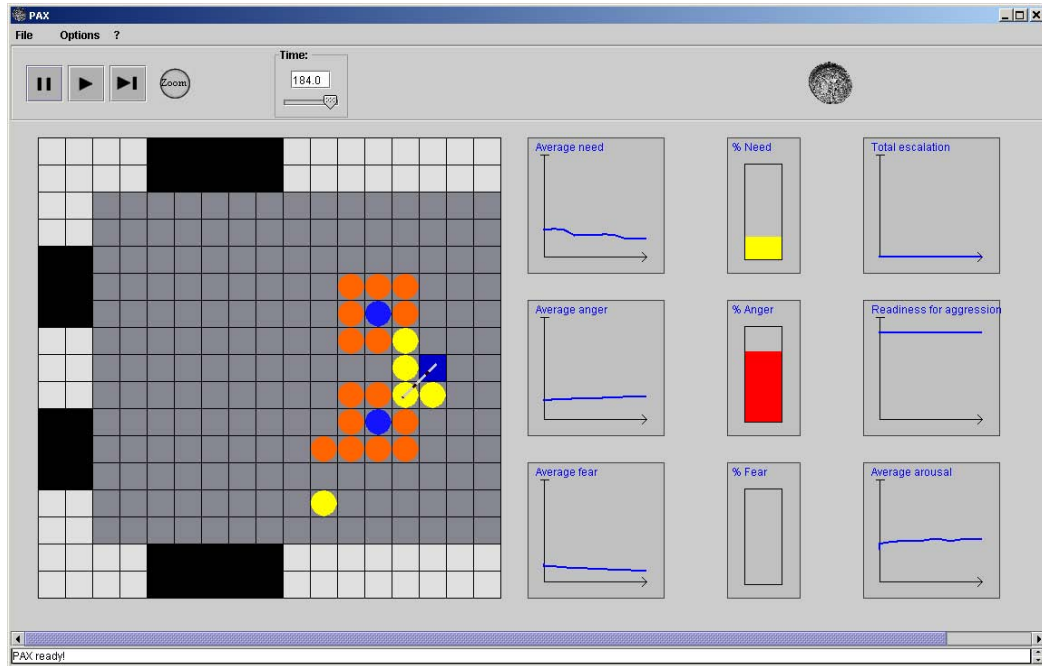


Figure 5 Food Distribution Scenario in PAX.

The Working Group was able to model the food distribution process to a satisfactory extent, with the ability to better understand the escalation and de-escalation process. It was also noted that the “Gandhi” strategy of always attempting to pacify the civilians may seem to be good for several measures of effectiveness, but is not always the best choice. Furthermore the “Zero Tolerance” strategy, whereby the soldiers always defend, may lead to very little escalation but may jeopardize future operations. Riding on the success of this basic model framework, PAX developers subsequently added features, such as a polling station, that allowed the Working Group to investigate an Election scenario.

D. CHOICE OF MODELING PLATFORM

In using MANA for the Food Distribution scenario, we see that the escalation process may not be modeled with sufficient fidelity. The food distribution process itself was not really modeled. In terms of the MOEs that could be recorded, they are largely limited to combat-related measures, such as

attrition rates. Furthermore, little or no capabilities exist for modeling human emotions such as fear and anger.

From these and other studies, and PAX's primary focus on civilian characteristics and human behaviors, we decided that PAX looked like a more promising approach to gain insights into the checkpoint scenario.

E. MEASURES OF EFFECTIVENESS FOR PEACE SUPPORT OPERATIONS

The Defense Modeling and Simulation Office (DMSO) online M&S glossary (DODD 5000.59-M) defines an MOE as "A qualitative or quantitative measure of the performance of a model or simulation or a characteristic that indicates the degree to which it performs the task or meets an operational objective or requirement under specified conditions" [Online M&S Glossary DODD5000.59-M, 2004].

Based on the preceding discussion, it is obvious that a new set of MOEs need to be defined to better reflect the unique nature of peacekeeping and peace support operations. Traditional attrition-biased MOEs such as number of BLUE or RED forces killed or injured would not serve the purpose here.

The following list of MOEs, not intended to be exhaustive, contains examples of some of the more appropriate measures to be considered when assessing the success or failure of peace support operations.

1. Average Fear

Peacekeeping forces deal with civilians more often than with combatants. When an operation is completed, it is important to understand the anxiety of the general population by looking at the number of people who would be left fearful, as this could affect long term operations when the peacekeeping forces may need to return.

2. Average Anger

Similar to fear, anger could be another dimension of measuring the wellness of the population. Clearly, future peacekeeping operations would suffer if the civilians were left angry and this could lead to further violence and unstable situations.

3. Average Need/Election Motivation

One of the reasons the peacekeeping forces are put in place is to restore law and order so that the civilians are able to carrying out their routine activities. In a food distribution scenario, the number of people fed (or number of food packages distributed) would seem to be an obvious choice for a MOE. It is also possible to look at the average need of the population over time, where an increasing need may indicate that the operation does not achieve its objective of fulfilling the needy civilians. In the case of a polling scenario, the election motivation of the voters may again be used to gauge the amount of need that could be fulfilled during the operation.

4. Number of Civilians Who Crossed Checkpoint

Checkpoint manning is one of the more common and basic operations in which peacekeeping forces are engaged. When investigating the effects of different checkpoint configurations, measuring the number of civilians who manage to cross the checkpoint is a means of assessing the efficiency or success of crowd control situation.

5. Total Escalation

The interaction between warring groups or between civilians and peacekeeping forces can often lead to violent situations. There could be an increased amount of threatening and aggressive acts, including verbal and physical attacks. Hence it is important to measure such interactions as an indicator of the level of escalation. Furthermore, by tracking this measure, it is also possible to understand the de-escalation process.

By building an abstraction of a checkpoint scenario of a representative Iraqi town in PAX, we investigate some of the MOEs mentioned above and discover factors that are critical to the success of the peacekeeping operations.

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III. BUILDING THE MODEL

A. CHAPTER OVERVIEW

Chapter III gives a brief introduction to PAX, with the aim of describing some of the salient features that are particularly useful in building the model. It is not intended to be a comprehensive guide and hence the readers are advised to refer to the PAX Users' Manual [Schwarz, 2003] for details.

B. BUILDING THE SCENARIOS

The baseline scenario depicts a typical town setup, representative of an Iraqi town. There are soldiers manning a checkpoint as part of the peacekeeping operations to ensure law and order in the area.

Figure 6 shows a model abstraction of the scenario in PAX.

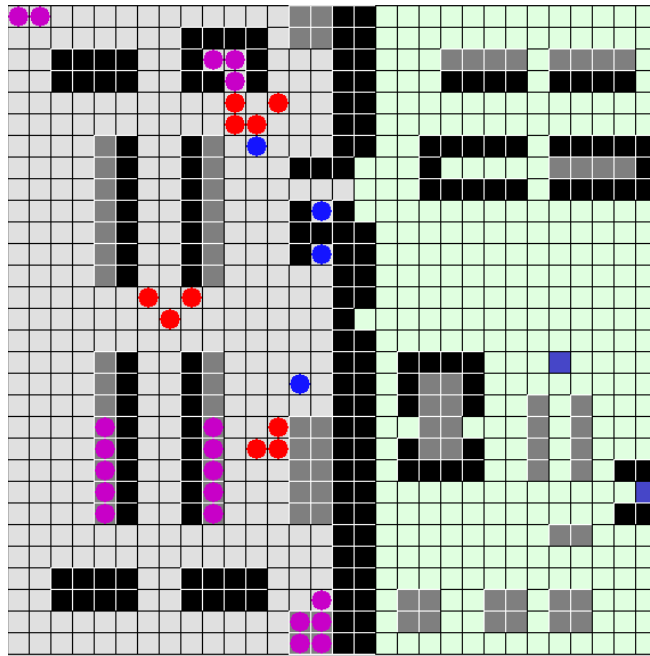


Figure 6 Basecase Scenario.

The basecase scenario depicts a checkpoint guarded by an Admission Control Soldiers (Adm), with a Reserve Squad (Res) on standby in the locality and two other Squads (Res) patrolling in the vicinity.

There are two groups of civilians, identified primarily by their motivation and permission to get across the checkpoint for certain purposes, such as going to a marketplace. One group has motivation and permission to cross the checkpoint. The other group of civilians does not have permission, and might create havoc in the area by acting aggressively towards the normal civilians, and even towards the soldiers.

There are 20 normal civilians (NormalCivs) with election motivation to go through the checkpoint to the other side of the town and another 10 aggressive civilians (AggressiveCivs) divided into three clusters throughout the town that are going to disrupt the operation. The normal civilians are initially located to the northwestern and southwestern parts of the town, and they appear purple, indicating that their current leading emotion is ElectionMotive. On the same note, the aggressive civilians are initially located nearer to the checkpoint, and they appear red, indicating that their current leading emotion is Anger. We will discuss in subsequent sections in more details how their colors may change during the course of the simulation.

1. Naming of Civilian Groups

As part of the modeling abstraction, civilians were divided into 2 groups, primarily distinguished by their *ElectionMotive* values. The original scenario had this group of civilians having this “voting need” and hence will have the propensity to want to move across the checkpoint. They were given an arbitrary name of NormalCivs (normal civilians) and assigned Group 1 in PAX. These were sometimes referred to as voters too, due to the use of “voting need”. However, subsequent experiments went ahead and investigated the situations when the characteristics of this group of NormalCivs were varied through an extensive range. Some cases would end up with this group behaving aggressively, too, although they still have the motivation and permission to cross the checkpoint.

On the same note, the Group 2 civilians were labeled *AggressiveCivs* (aggressive civilians) as they were set to have zero *ElectionMotive* and were not allowed to pass through the checkpoint. They were originally intended as disturbers to the area. Similarly, due to the wide range of values used in the experiments, there were cases that this group of civilians did not necessarily act aggressively relative to the Group 1 civilians.

Hence the main distinction between the groups was the *ElectionMotive* and *GroupNumber*. Only civilians from Group 1 were allowed to pass through the checkpoints. This could be thought of as pass-holders that were permitted to move across town. Group 2 civilians would then be the non-pass-holders.

Throughout this document, data sets, tables, chart and equations may reference the terms *NormalCivs* and *AggressiveCivs* only. In hindsight, the names *PassHolders* and *NonPassHolders* would be more appropriate.

C. PAX

This section provides an introduction to PAX, along with the model abstraction of the scenario described above. It also highlights some of the key features unique to PAX.

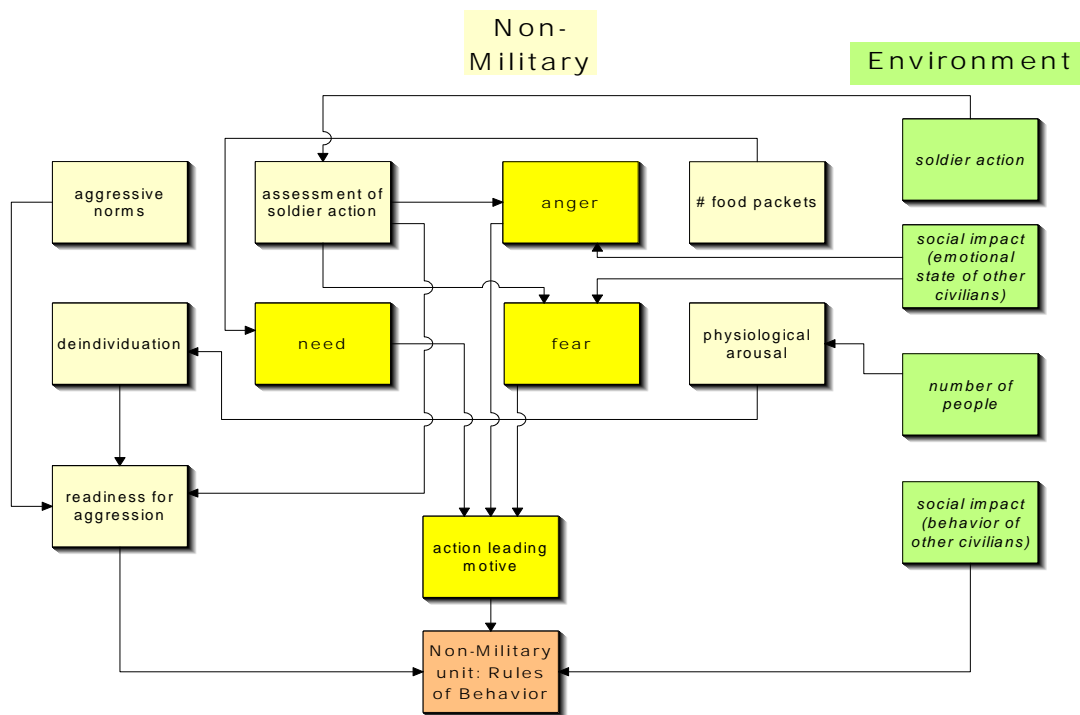
1. Background

Since Germany achieved reunification and regained full sovereignty in 1990, and under the German Constitution, she has been participating actively in peacekeeping and peace support operations. In recent years, the German military and defense industry has also been an important partner in the Project Albert development.

As opposed to conventional combat, the forces performing peacekeeping operations do not seek to engage the “enemies” in fire-fight. More often than not, the opponents are usually non-combatants, thus different tactics and doctrines are required to deal with them. Furthermore, the peacekeeping forces need to

carry out their missions with minimal use of force, and at the same time ensure the safety of the public and their own safety.

One of the main factors that set PAX apart from other agent-based models is its Civilian Behavior Model. PAX is developed with inputs and participation from experts in social psychology, systems theory, operations research and military advisors, proficient in peace support operations. Figure 7 [Schwarz, 2003] shows a simplified internal model and how the main psychological drivers (anger, need and fear) may be influenced by external factors from the environment (soldiers' actions and behaviors of other civilians).



2. PAX Start-up

The PAX start-up screen provides the user with the interface to perform step-by-step actions to set up of the models for experiment and analysis.

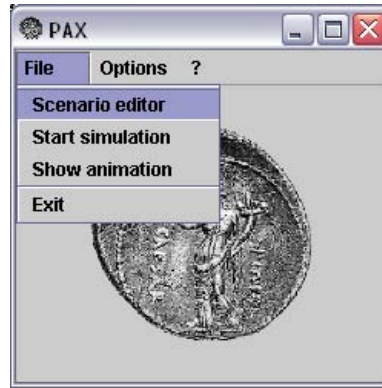


Figure 8 Drop-down Menu from the PAX GUI.

From the drop-down menu shown in Figure 8 above, the user can choose to run the Scenario Editor for creating new or running existing scenarios. The Start Simulation tab will run a simulation based on the scenario and random seed chosen and the specified length of execution. The user may then view the animation and simulation results by choosing the Show Animation tab.

3. PAX Scenario Editor

The PAX Scenario Editor defines the “playing field” on which agents interact. A two-dimensional representation of a town or any area of operation may be created by defining areas as either “Normal”, “Built-up” or “Barrier”. Figure 9 shows the abstraction of a typical town with rows of houses, and separated by either man-made barrier such as fences or natural barrier such as a river. In order to move between the different areas, there is a need to cross the checkpoint, manned by squads of soldiers.

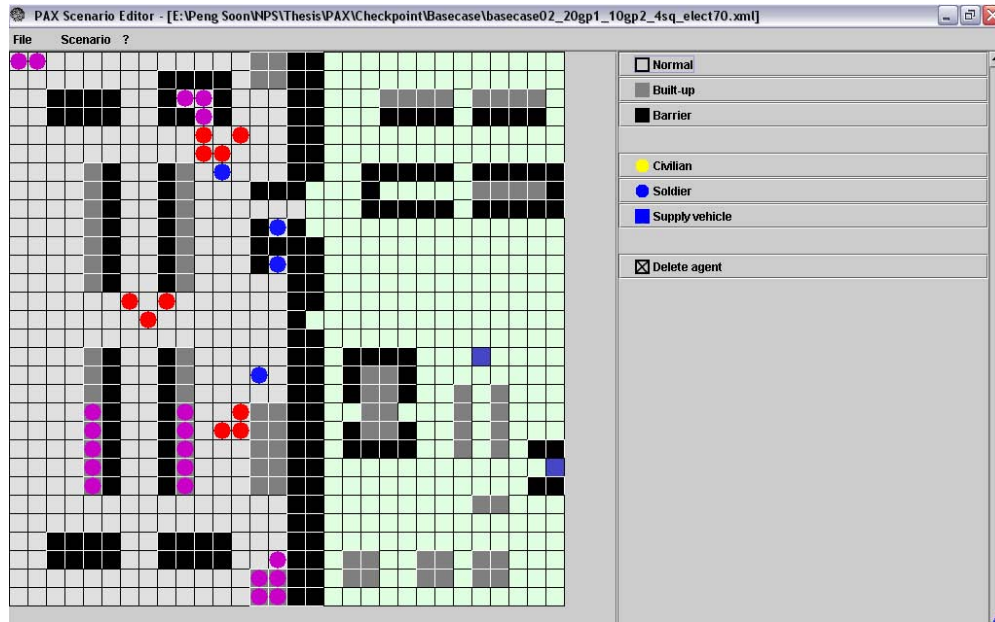


Figure 9 PAX Scenario Editor.

a. General

Once the scenario editor is invoked, some top-level generic parameters may be defined so that all scenarios created will have the same setup. Figure 10 shows the setup screen for the Scenario Parameters.

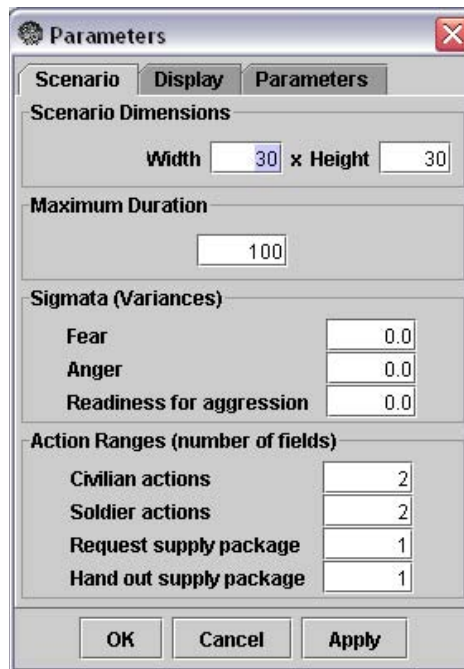


Figure 10 Scenario Parameters.

(1) Scenario Dimension. The maximum allowable size of the scenario dimension is 30x30. Each square is identified with a coordinate system (x / y), whereby (0/0) is the left-bottom grid square.

(2) Maximum Duration. The default duration used for the length of simulation time. Value may be changed when setting up the scenario for each simulation run. Unit used is simulation time-unit.

(3) Display. When the “Auto” box shown in Figure 11 is checked, the map will be automatically adjusted to fit the display area for ease of viewing without the need for constant scrolling.

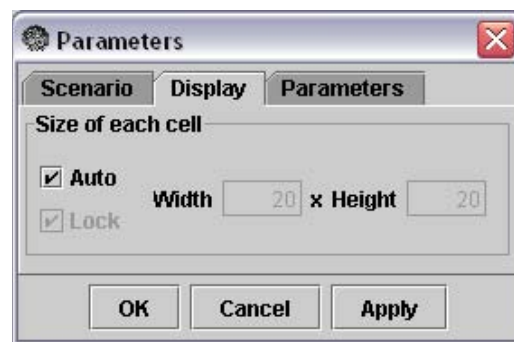


Figure 11 Display Parameters.

(4) Agent Parameters. When a box is checked, it allows the user to define values for that particular characteristic of the agent, according to modeling needs. Figure 12 shows all agent parameters checked except “PC_Fear”, “PC_Anger” and “Decrease of anger on success”, where the default settings will be used instead.

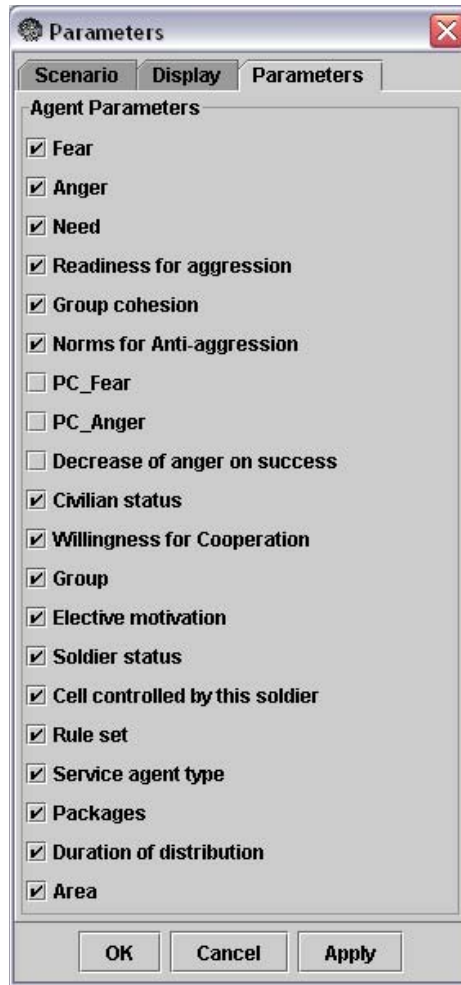


Figure 12 Agent Parameters.

(5) Custom Parameters. For additional modeling needs, custom parameters allow the user to explore the more advanced features. Figure 13 shows the definition of Cell Transition.

6	7	8
4	Grid	5
1	2	3

Figure 13 Direction of Cell Transition.

For example, to define the cell (16/22) to be unidirectional from West to East, Figure 14 shows the syntax used for the parameter is /PAX/Environment/Uebergang[x-coord of cell][y-coord of cell][direction of cell transition]. .

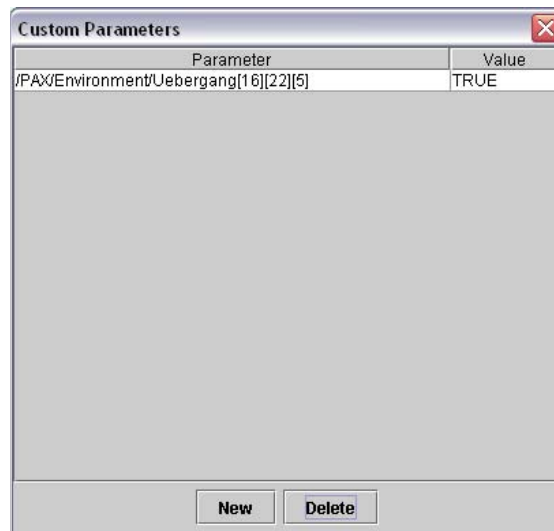


Figure 14 Custom Parameters for Unidirectional Cell Transition.

The first version of PAX was developed in German and subsequently English releases may not address all features, thus the appearance of German in this example as a legacy issue.

To define the cell as bi-directional, simply add another line for the custom parameters and define the direction of cell transition in the opposite direction.

b. Type of Field

In the PAX scenario map, areas may be defined in such a way as to limit the movement of agents across different fields.

(1) Normal. Normal cells are the sort of cells that can be traversed by all agents. Figure 15 shows these cells may further be defined with Area of Influence (ranging from 0 to 3, represented as light-grey, light-blue, pink and light-green accordingly).

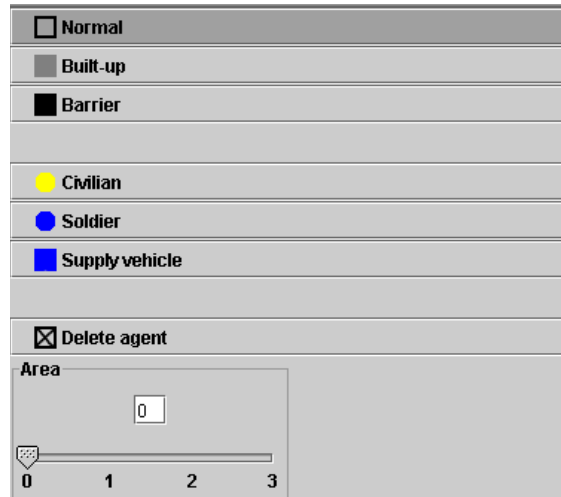


Figure 15 Area of Influence.

(2) Built-up. Built-up cells serve as a sort of refuge for civilian agents that are frightened or have already received a supply package or cast a vote.

(3) Barrier. Barrier cells cannot be traversed by any agent and can be regarded as some sort of obstacle, be it natural or man-made, such as a river, barbed wire or fence. Communication however, may still happen across barrier.

c. Type of Agents

There are currently three types of agents, namely the Civilian, Soldier and Supply Vehicle.

(1) Civilian. The initial states of a civilian agent may be setup to be representative of a typical character through the parameters such as “Fear”, “Readiness for aggression”, “Anger”, “Need” and others. By defining civilians to belong to different groups, it is possible to model groups with different goals, leadership and study the behaviors and interactions between these groups. Figure 16 shows how these characteristics may be varied with a sliding bar as well as text entry of the desired values, on an absolute scale of 0 to 100.

A civilian may also be defined as a leader of the group, by selecting the “Leader” on the Civilian Status tab.

Parameter	Value
Fear	30
Readiness for aggression	20
Anger	20
Group cohesion	20
Need	0
Norms for Anti-aggression	10
Elective motivation	70
Group	1
Civilian status	Normal
Willingness for Cooperation	80

Figure 16 Civilian Parameters.

Most of these parameter names are self-explanatory, but special attention is brought to the term “Norms for anti-aggression”. This agent parameter is used to indicate the agent’s internal state and familiarity with aggressive environments. A high value indicates that the civilian is not used to behaving in an aggressive or violent way.

(2) Soldier. The drop-down menu shown in Figure 17 indicates that soldier status can be set to Normal, Admission Control or

Reserves. However, only Admission Control and Reserves are currently implemented.

☐ Normal
☐ Built-up
☐ Barrier
☐ Civilian
☒ Soldier
☐ Supply vehicle
☒ Delete agent

Soldier status: Reserves
 Normal
 Admission control
 Reserves

Cell controlled by this soldier: <NONE>

Rule set: 1

1 2 3 4 5 6 7 8 9 10

Figure 17 Soldier Parameters.

A Soldier's actions are governed by the specified Ruleset, that remains constant during the run. Although the numbers on the sliding bar for Soldier Ruleset range from 1 to 10, there are only 6 implemented currently. Tables 3-8 define the logic behind each Ruleset. Note that there are two possible actions of civilian and three possible dominating group behaviors. Each column should be interpreted as a situation as a possible combination of an action of civilian and a dominating group behavior. Under each of these conditions, the soldiers will execute the appropriate actions. Some of the Rulesets are popularly referred to by names which better reflect the key principles governing these rules. For example, Ruleset 1 is also known as PSO Manual as the soldiers would engage the civilians with a wider range of actions for each appropriate situations, much to the "teaching" of the PSO Manual. Ruleset 4 is commonly known as Gandhi strategy as it employs the "always pacify" action all the time. Other the other hand, Ruleset 6 is referred to as Zero

Tolerance since the soldiers always defend regardless of civilians' actions or dominating group behavior.

Ruleset 1 (PSO Manual) allows the soldier a full range of possible actions (as Table 3 shows).

Conditions		Rules					
		1	2	3	4	5	6
1	Action of Civilian: Attack	Y	Y	Y			N
2	Action of Civilian: Threaten				Y	Y	N
3	Dominating Group Behavior: Attack	Y					
4	Dominating Group Behavior: Threaten		Y				
5	Dominating Group Behavior: Not aggressive			Y	N	Y	
Actions							
1	"Defend"	X					
2	"Threaten"		X		X		
3	"Pacify"			X		X	
4	"Wait"						X

Table 3 Ruleset 1 – PSO Manual.

In contrast to Ruleset 1, under situations 3 and 5, the soldier will wait instead of pacify when Ruleset 2 is used (as Table 4 shows).

Conditions		Rules					
		1	2	3	4	5	6
1	Action of Civilian: Attack	Y	Y	Y			N
2	Action of Civilian: Threaten				Y	Y	N
3	Dominating Group Behavior: Attack	Y					
4	Dominating Group Behavior: Threaten		Y				
5	Dominating Group Behavior: Not aggressive			Y	N	Y	
Actions							
1	"Defend"	X					
2	"Threaten"		X		X		
3	"Pacify"						
4	"Wait"			X		X	X

Table 4 Ruleset 2.

In contrast to Ruleset 1, under situation 1, the soldier will threaten instead of defend when Ruleset 3 is used (as Table 5 shows).

Conditions		Rules						
		1	2	3	4	5	6	
1	Action of Civilian: Attack	Y	Y	Y			N	
2	Action of Civilian: Threaten				Y	Y	N	
3	Dominating Group Behavior: Attack	Y						
4	Dominating Group Behavior: Threaten		Y					
5	Dominating Group Behavior: Not aggressive			Y	N	Y		
Actions								
1	"Defend"							
2	"Threaten"	X	X		X			
3	"Pacify"			X		X		
4	"Wait"						X	

Table 5 Ruleset 3.

The next three Rulesets permit the soldier only one possible action other than "Wait". Table 6 shows that the soldier will always pacify regardless of the dominating group behavior when Ruleset 4 (the Gandhi strategy) is used.

Conditions		Rules						
		1	2	3	4	5	6	
1	Action of Civilian: Attack	Y	Y	Y			N	
2	Action of Civilian: Threaten				Y	Y	N	
3	Dominating Group Behavior: Attack	Y						
4	Dominating Group Behavior: Threaten		Y					
5	Dominating Group Behavior: Not aggressive			Y	N	Y		
Actions								
1	"Defend"							
2	"Threaten"							
3	"Pacify"	X	X	X	X	X		
4	"Wait"						X	

Table 6 Ruleset 4 - Gandhi.

In contrast to Ruleset 1, the soldier will always threaten when Ruleset 5 is used (as Table 7 shows).

Conditions		Rules					
		1	2	3	4	5	6
1	Action of Civilian: Attack	Y	Y	Y			N
e	Action of Civilian: Threaten				Y	Y	N
3	Dominating Group Behavior: Attack	Y					
4	Dominating Group Behavior: Threaten		Y				
5	Dominating Group Behavior: Not aggressive			Y	N	Y	
Actions							
1	"Defend"						
2	"Threaten"	X	X	X	X	X	
3	"Pacify"						
4	"Wait"						X

Table 7 Ruleset 5.

Ruleset 6 is also called "Zero Tolerance". In contrast to Ruleset 1, the soldier will always take defensive action (as Table 8 shows).

Conditions		Rules					
		1	2	3	4	5	6
1	Action of Civilian: Attack	Y	Y	Y			N
2	Action of Civilian: Threaten				Y	Y	N
3	Dominating Group Behavior: Attack	Y					
4	Dominating Group Behavior: Threaten		Y				
5	Dominating Group Behavior: Not aggressive			Y	N	Y	
Actions							
1	"Defend"	X	X	X	X	X	
2	"Threaten"						
3	"Pacify"						
4	"Wait"						X

Table 8 Ruleset 6 – Zero Tolerance.

For a soldier designated as Admission Control, it is necessary to define a cell that it is controlling. Current implementation allows only civilians belonging to Group 1 through any cell pre-defined with directional

controls. Figure 18 shows the menu for determining the cell controlled by the soldier.

The interface consists of several sections:

- Agent Types:** A list of checkboxes for 'Normal', 'Built-up', 'Barrier', 'Civilian', 'Soldier', and 'Supply vehicle'. The 'Soldier' option is currently selected.
- Delete agent:** A checked checkbox.
- Soldier status:** A dropdown menu currently showing 'Reserves'.
- Rule set:** A text input field containing the number '1'.
- Cell controlled by this soldier:** A dropdown menu showing a list of directions: '<NONE>', 'NorthWest', 'North', 'NorthEast', 'West', 'East', 'SouthWest', 'South', and 'SouthEast'. 'NorthWest' is the selected option.

Figure 18 Soldier Controlled Cell.

(3) Supply Vehicle. When PAX was first developed, the scenario used was a food distribution scenario. The supply vehicle was modeled in such a way that it included implicitly a supply vehicle as well as a squad to guard and distribute the food packages. There is no movement associated with the supply vehicle. However, PAX was subsequently used to study a polling scenario and hence the supply vehicle may now be defined as either of the two service agent types, namely the supply vehicle or the polling station. Figure 19 shows the setting up of Supply Vehicle Parameters.

☐ Normal
☒ Built-up
☒ Barrier
☒ Civilian
☒ Soldier
☒ Supply vehicle

☒ Delete agent

Service agent type
 Polling station
 Polling station
 Supply Vehicle

Packages
 1
 1 34 67 100

Duration of distribution
 2.0
 0.0 5.0 10.0 15.0 20.0

Figure 19 Supply Vehicle Parameters.

When a Supply Vehicle is selected, the number of food packages (from 1 to 100) and the duration of distribution for each package may be defined, in order to simulate the food distribution process and the fact that the number of food packages is limited.

d. Restrictions

There are several restrictions the analyst must keep in mind while generating a scenario, in order to avoid problems within the simulation. The restrictions are as follows:

- At least one soldier must be present;
- At least one supply vehicle must be available;
- At least one building must be present;
- At least one area of influence must be defined;
- At least one soldier must be positioned in the influence area of the supply vehicle.

Current implementation limits the maximum number of civilians and squads to 50 and 5 respectively.

4. Running the Simulation

Once the scenario setup is complete, the simulation may be run and Specifying a random number seed makes the results reproducible at a later date. Animation helps to view and record results.

The user may define the desired length of time the simulation needs to run. However, setting too short a time may terminate the simulation prematurely and may end up with wrong observations and conclusions.



Figure 20 Setting Length of Simulation Time.

Figure 20 shows the simulation set to run for a pre-defined length of 200 seconds. The user is thus advised to try several values before determining the appropriate length of simulation time.

5. Animation of PAX

a. General

Unlike some other models, PAX does not provide real-time animation as the simulation is being executed. Instead, PAX performs the simulation and provides a separate animation function to read in the simulated results and provide the users with a playback tool.

The user may run the animation, pause and freeze at any time to study some points in of interest and continue thereafter. A rewind and fast-forward function allows the user to jump back and forth during the animation to

the desired segment. The user may also choose to step through the animation, to get detailed understanding dynamics as the scenario unfolds. Figure 21 shows a screen shot of the PAX animation.

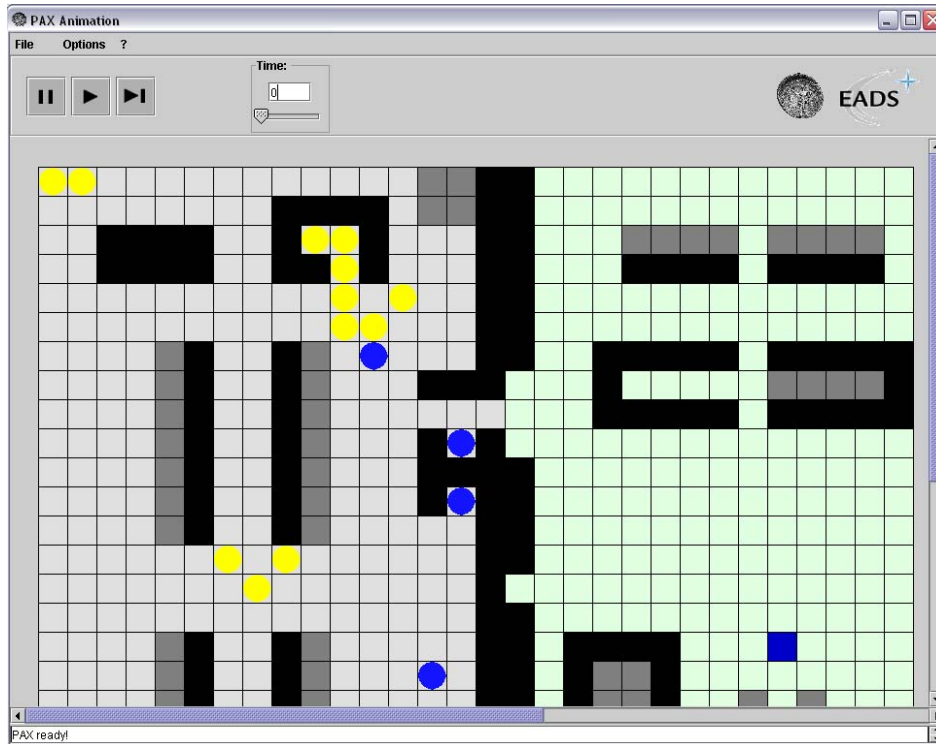


Figure 21 PAX Animation.

b. Interactions

Civilians are represented as solid filled circles, whose color changes during the animation according to the leading motive of the agent.

- Red: Anger
- Green: Fear
- Brown: Obedience
- Yellow: Need
- Purple: Election
- White: None

Interactions between agents are represented as directed colored dash lines:

- Blue from civilian: demanding supply packages
- Bright red from civilian: threatening
- Dark red from civilian: attacking
- Green from soldier: pacifying / calming
- Bright red from soldier: threatening
- Dark red from soldier: defending
- Black from supply vehicle: distributing supply packages

By looking at these colored “dots and lines”, where the direction of the flow of the dots during animation indicates the party performing the action, the user may have a better understanding of the stages the civilians go through, as well as the interactions between agents that could possibly resulted in such behaviors.

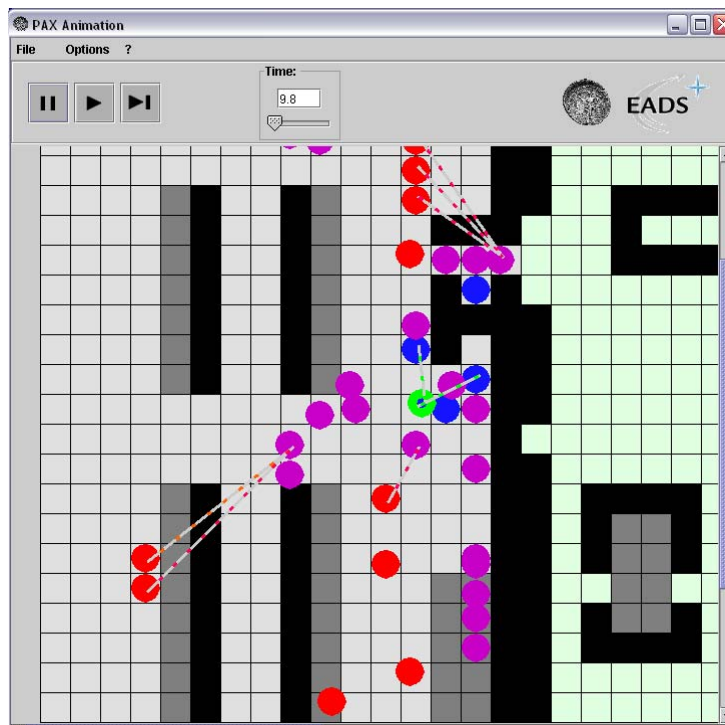


Figure 22 Interactions Between Agents.

c. Agent Information

By clicking on any agent during Animation, the agent information may be displayed. It serves to inform the user of the data contained in the specific agent, and are presented differently for the civilian, soldier and supply vehicle. Figure 23 shows an example of a civilian agent in cell (13/19) and its associated states and parameters.

The screenshot shows a window titled "Agent on field: (13/19)". It contains the following information:

Agent type:	Civilian
ID:	20
Group	1
Action:	Moving
Communication:	Waiting

Leading motive:	Elective motivation
Aim of Command:	No
Need:	0
<input type="text"/>	<input type="checkbox"/> Record need
El. motivation:	70
<input type="text"/>	<input type="checkbox"/> Record elective motivation
Anger:	60
<input type="text"/>	<input type="checkbox"/> Record anger
Fear:	86
<input type="text"/>	<input type="checkbox"/> Record fear
Obedience	0
<input type="text"/>	<input type="checkbox"/> Record Obedience

Deindividuation	15
<input type="text"/>	<input type="checkbox"/> Record de-individuation
Readiness for aggression	29
<input type="text"/>	<input type="checkbox"/> Record aggressiveness

☐ Display plan of actions

Figure 23 Individual State of a Civilian Agent.

From Figure 23 above, the leading motive of the particular civilian with ID 20 is "Election Motivation", although the anxiety is quite high as apparent from the relatively high values of Anger and Fear. The Deindividuation factor is

relatively low, indicating that group behavior and emotions around this civilian still have relatively little impact on changing his behavior. Deindividuation is the phenomenon when an individual is influenced by group dynamics and takes on the group behavior, thus temporarily losing their “individuality”.

By clicking on any Soldier, information on its state as shown in Figure 24 would be presented.

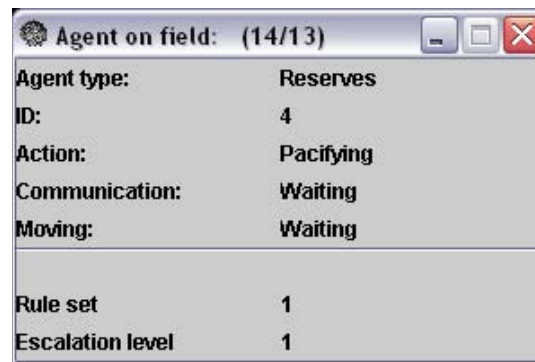


Figure 24 Information on Soldier Agent.

Limited information about the status of Soldier agents is provided. In this instance, the Soldier with ID 4 is currently pacifying the civilians, employing Ruleset 1 and the escalation level is currently low.

d. Statistical Graphs

PAX provides some basic statistical graphs during animation to allow the user a quick glance of the current states of some of the following MOEs:

- (1) Average Election Motivation/Need.
- (2) Average Anger.
- (3) Average Fear.
- (4) Total Escalation.
- (5) Readiness for Aggression.
- (6) Average Arousal.

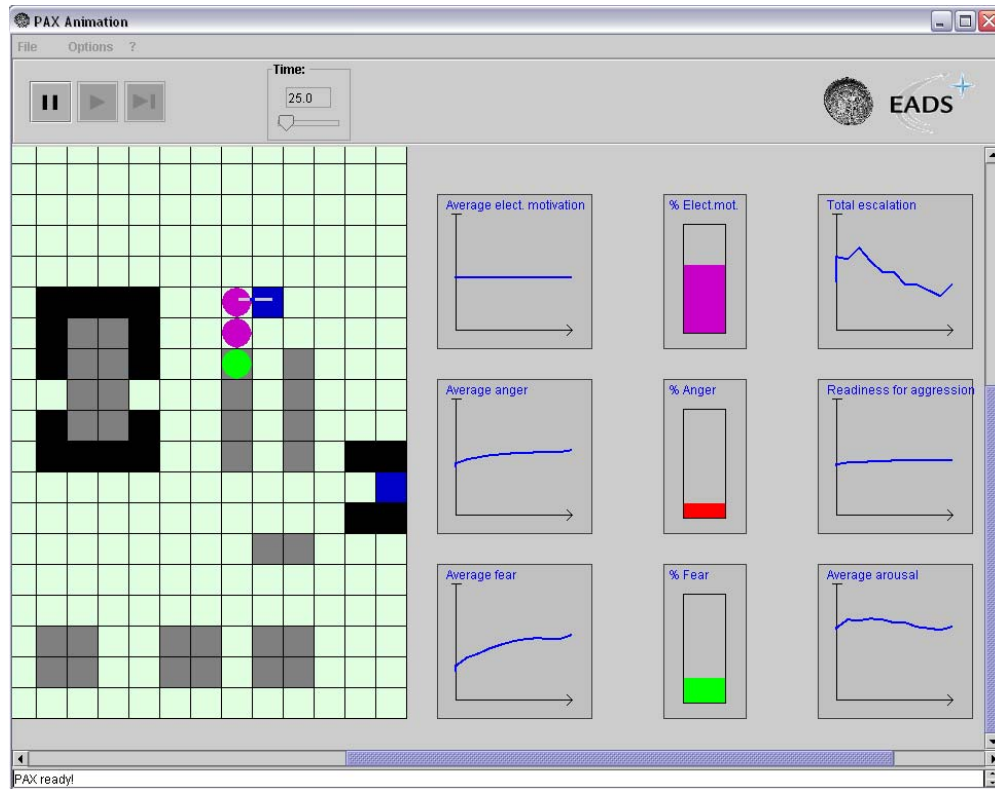


Figure 25 Statistical Graphs.

From Figure 25 below, we can see that in this scenario, Average Fear and Anger had increased gradually over time. There was some escalation in the early stages, but the de-escalation process was rather successful.

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IV. ANALYSIS METHODOLOGY

A. CHAPTER OVERVIEW

This chapter begins with a brief discussion of the design of experiments, to include the factors and levels that are appropriate for this research purpose and the benefits of employing a Near Orthogonal Latin Hypercube design. See Kleijnen et al. (2004) for a general discussion of designing simulation experiments. The data collected from these experiments will then be analyzed with the statistical software package JMP. Regression models will be developed for the various MOEs in an attempt to identify critical or significant factors that could provide insights to the scenario.

B. DESIGN OF EXPERIMENTS

The number of factors of interest that an experiment seeks to study depends on many things, some of which are listed as follows:

- Purpose and objective of research
- MOEs defined
- Computing hardware resource limitations
- Model software limitations
- Analyst's experience (or inexperience)

For each factor, the number of admissible levels may range from two, as in the case of an ON/OFF switch or HIGH/LOW setting, to hundreds or thousands, as in the case of distances or other continuous-valued factors.

In an ideal situation, it would be great if the experiment could examine all possible combinations of factors. However, such a case is rarely practical or possible unless the number of factors and the numbers of potential levels for each factor are all small. In full factorial design, experimental runs are performed at every combination of the factor levels. For example, a factorial experiment

with a two-level factor, a three-level factor and a four-level factor will have $2 \times 3 \times 4 = 24$ runs [JMP®, Design of Experiments, Version 5.1, 2003]. Figure 26 shows how the number of design points grows exponentially as a function of the number of levels for a full factorial design.

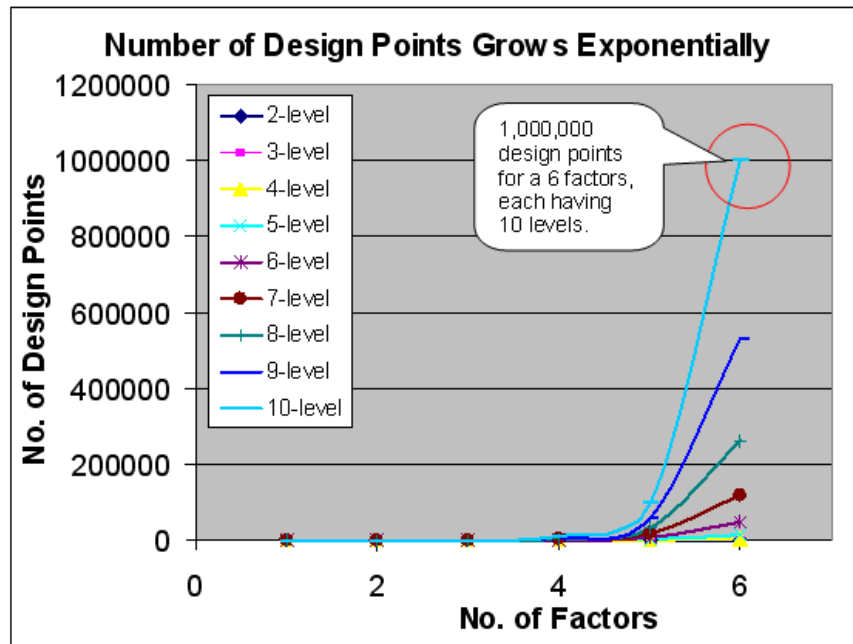


Figure 26 Number of Design Points Grows Exponentially.

It is thus usually not practical to implement a full factorial design, given the number of factors and levels in the experiments. Latin Hypercube designs provide an excellent set of alternatives, because of their space filling behavior and near orthogonality. By using the NOLHDesigns spreadsheet [Sanchez, 2004], adopted from the designs developed by Cioppa [Cioppa, 2002] the high and low values for each factor are entered and the spreadsheet will automatically generate the design points. For the basecase scenario used in this thesis, which is an 18-factor experiment, there are 129 design points generated. Figure 27 shows a sample of some of the design points.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
2	low level	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	high level	6	6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	0	0	0
4	factor name	ruleAdm	ruleRes	aggInitAngr	aggAngDyn	aggInitRFA	aggInitFear	aggFearDyn	aggNormsAntiAgg	aggGroupCoh	voterInitAngr	voterAngDyn	voterInitRFA	voterInitFear	voterFearDyn	voterNormsAntiAgg	voterGroupCoh	voterAngDecOnSuccess	voterElectMotive				
5		2	3	39	45	34	69	56	76	55	93	77	76	60	100	93	62	84	54	0	0	0	0
6		5	3	43	46	9	45	42	20	48	38	92	59	62	95	73	80	91	58	0	0	0	0
7		3	5	0	27	41	16	75	65	61	57	47	16	48	86	99	63	55	15	0	0	0	0
8		4	5	30	37	44	76	7	41	27	46	41	38	34	98	67	97	61	36	0	0	0	0
9		1	3	55	23	10	53	36	93	100	63	11	99	85	27	45	44	88	67	0	0	0	0
10		5	3	70	1	40	33	59	4	25	12	18	100	63	48	31	34	92	88	0	0	0	0
11		3	6	76	29	16	23	24	94	96	73	70	10	0	11	47	31	91	34	0	0	0	0
12		4	5	89	6	34	92	87	2	30	21	49	9	16	28	34	43	47	9	0	0	0	0
13		1	1	26	20	20	98	73	43	73	85	74	27	59	26	95	80	78	98	0	0	0	0
14		6	1	22	27	12	10	20	55	20	14	48	13	70	12	91	45	73	70	0	0	0	0
15		1	6	48	28	31	7	77	22	62	83	16	54	27	23	75	94	72	21	0	0	0	0
16		6	6	25	38	14	100	51	91	28	31	24	67	25	44	84	54	59	20	0	0	0	0
17		3	2	95	18	41	72	5	36	66	89	1	21	91	73	32	11	77	83	0	0	0	0
18		5	2	92	35	9	23	91	54	20	39	2	32	84	94	36	21	67	48	0	0	0	0

Figure 27 NOLHC Design Spreadsheet.

Since our factor ranges are not divisible by 129, some rounding will occur for the resulting factor levels. This means we must check to make sure that the resulting design still has good orthogonality properties. By looking at the correlation matrix in Figure 28 we observe that the correlation coefficients between any two factors are very low with the highs not exceeding 0.1, indicating fairly good orthogonality.

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12	Column 13	Column 14	Column 15	Column 16	Column 17	Column 18
Column 1	1.000																	
Column 2	0.001	1.000																
Column 3	0.005	0.022	1.000															
Column 4	0.014	0.012	0.000	1.000														
Column 5	0.010	-0.043	0.000	0.000	1.000													
Column 6	0.005	-0.030	-0.001	-0.002	0.004	1.000												
Column 7	0.012	0.010	0.001	-0.006	-0.002	0.004	1.000											
Column 8	0.020	0.002	0.000	0.000	-0.005	0.005	-0.004	1.000										
Column 9	0.000	-0.030	-0.005	0.003	0.001	0.000	-0.002	0.002	1.000									
Column 10	-0.078	-0.012	-0.001	0.000	0.000	-0.002	-0.006	0.004	0.000	1.000								
Column 11	-0.010	0.017	0.003	-0.004	-0.001	0.000	0.000	-0.002	0.000	0.004	1.000							
Column 12	-0.012	0.021	-0.002	0.004	0.002	0.003	0.000	0.006	0.001	-0.004	0.003	1.000						
Column 13	0.046	-0.001	-0.002	0.001	0.002	0.000	-0.003	0.000	0.003	0.004	0.003	-0.004	1.000					
Column 14	-0.022	-0.014	-0.001	-0.001	0.001	-0.004	0.001	-0.001	0.001	0.004	0.006	-0.001	0.002	1.000				
Column 15	-0.002	-0.042	0.001	0.000	-0.002	0.005	-0.005	0.003	0.003	-0.004	0.004	0.001	0.004	-0.002	1.000			
Column 16	-0.005	0.000	0.001	-0.003	0.000	0.004	-0.005	0.004	-0.001	0.001	-0.002	0.003	-0.004	0.004	-0.001	1.000		
Column 17	0.026	-0.011	0.004	0.000	-0.003	0.002	0.001	0.003	0.005	0.001	-0.002	0.004	0.003	0.005	-0.004	-0.001	1.000	
Column 18	0.013	-0.082	0.003	0.002	0.002	-0.004	-0.001	0.003	0.001	0.002	-0.004	-0.003	0.002	-0.002	0.003	0.002	0.001	1.000

Figure 28 The Correlation Matrix.

In order to generate more design points and provide better space filling, the third column of the Latin Hypercube (since the Rulesets have different ranges of values) was wrapped around to the last column. The first and second columns were left untouched since they represent the values of Rulesets (from 1 through 6) used for Admission Control Soldiers and Reserve Soldiers, respectively. In this way, it is possible to look at double the amount of design points and yet maintain or improve the orthogonality. Below is a sample of the spreadsheet with the new design points.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
2	low level	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	high level	6	6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	0	0	0
4	factor name	ruleAdm	ruleRes	voteElectMotive	aggInitAnger	aggAngDyn	aggInitRFA	aggInitFear	aggFearDyn	aggNormsAntiAgg	aggGroupCoh	voterInitAnger	voterAngDyn	voterInitRFA	voterInitFear	voterFearDyn	voteNormsAntiAgg	voteGroupCoh	voteAngDecOnSuccess				
5		2	3	39	45	34	69	56	76	55	93	77	76	60	100	93	62	84	54	0	0	0	0
6		5	3	43	46	9	45	42	20	48	38	92	59	62	95	73	80	91	58	0	0	0	0
7		3	5	0	27	41	16	75	65	61	57	47	16	48	86	99	63	55	15	0	0	0	0
8		4	5	30	37	44	76	7	41	27	46	41	38	34	98	67	97	61	36	0	0	0	0
9		1	3	55	23	10	53	36	93	100	63	11	99	85	27	45	44	88	67	0	0	0	0
10		5	3	70	1	40	33	59	4	25	12	18	100	63	48	31	34	92	88	0	0	0	0
11		3	6	76	29	16	23	24	94	96	73	70	10	0	11	47	31	91	34	0	0	0	0
12		4	5	89	6	34	92	87	2	30	21	49	9	16	28	34	43	47	9	0	0	0	0
13		1	1	26	20	20	98	73	43	73	85	74	27	59	26	95	80	78	98	0	0	0	0
14		6	1	22	27	12	10	20	55	20	14	48	13	70	12	91	45	73	70	0	0	0	0
15		1	6	48	28	31	7	77	22	62	83	16	54	27	23	75	94	72	21	0	0	0	0
16		6	6	25	38	14	100	51	91	28	31	24	67	25	44	84	54	59	20	0	0	0	0
17		3	2	95	18	41	72	5	36	66	89	1	21	91	73	32	11	77	83	0	0	0	0
18		5	2	92	35	9	23	91	54	20	39	2	32	84	94	36	21	67	48	0	0	0	0

Figure 29 Design Points Obtained by Wrapping Third Column Around Last Column.

The procedures described above created 258 design points for the NoLeader basecase scenario. The maximum pairwise correlation for this expanded design was still limited to highs of not more than 0.1. The same procedures were applied to two more scenarios, namely MoreCoopLeader and LessCoopLeader scenarios. In these cases, an additional column was added to indicate the LeaderCooperativeness values, which were set to 60 and 40 respectively. In total, there were 774 design points generated.

C. RUNNING THE EXPERIMENTS AND DATA COLLECTION

The NOLH design set up in the previous section generated 6 experiments with 129 design points each. For ease of data referencing, the following conventions were used:

- Experiment A – NoLeader (original NOLH matrix)
- Experiment AA – NoLeader (NOLH matrix column shifted)
- Experiment B – MoreCoopLeader (original NOLH matrix)
- Experiment BB – MoreCoopLeader (NOLH matrix column shifted)
- Experiment C – LessCoopLeader (original NOLH matrix)
- Experiment CC – LessCoopLeader (NOLH matrix column shifted)

1. **PAX Experiment Editor**

The PAX Experiment Editor provides the user with a graphical user interface to generate multiple excursions of the basecase scenario created with the PAX Scenario Editor. A study.xml file was generated for each experiment.

2. **OldMcData for PAX**

OldMcData is a software application developed by MITRE Corporation to do small data farming runs, including multiple replications of a single excursion, on a single machine. In this way, the user may conduct small scale experiments on a local machine, without requiring the resources on the MAUI High Performance Computing Center (MHPCC).

Currently there is no graphical user interface and thus the user is required to manipulate files using the command lines in the DOS prompt window. The application also supports runs across multiple machines by using the Condor open-source distributed computing environment.

A postprocessor is included to help the user combine all the results in the various excursions into a single comma-separated (csv) file. This file contains the input settings as well as the outputs at end of each simulation run. The data may now be used for further analysis with a wide variety of data analysis software packages.

For details of running commands in OldMcData, refer to User's Guide, OldMcData – The Data Farmer, version 1.0 by Stephen C. Upton, The MITRE Corporation.

3. Collating the Results

Results from the 6 experiments described in previous section were each provided in an individual csv file. All these were combined in a single csv file after carefully sorting the individual csv files so the column headings were matched. This file contained 774 rows of data, including the input settings as well as the MOEs that will be recorded by PAX.

D. LINEAR REGRESSION ANALYSIS

Linear regression attempts to discover the relationship between the inputs and the responses by fitting linear models to the data points. JMP provides a “Fit Model” function with options to select the appropriate models and regression techniques and output the statistics of the fitted model for further analysis.

This thesis adopted a stepwise linear regression approach, whereby regressor terms were brought into and out of the model as determined by the “Prob to Enter” and “Prob to Leave” respectively. The values chosen for these probabilities required a balance between a need to fit a model to achieve a high R^2 versus the ease of understanding the model. R^2 always increases when terms are added to the model, at the risk of making the model too complicated and unusable. Judgment is required to fine-tune the model and select the final regression model. In each of the scenario, a full second-order model was setup to investigate the main effects, quadratic effects and two-way interactions.

For each MOE, the initial regression model considered all the data points as a single set. Subsequently the data is subset into two groups of 258 and 516 points each, representing the cases when there was a civilian leader absent and present respectively. Similar stepwise regression techniques were applied to each data subset to formulate the regression models.

1. Introduction to JMP

JMP is a statistical analysis software package that emphasizes interactive techniques to explore data, to discover patterns, and to fit models. JMP provides a rich variety of graphical visualization methods that helps an analyst better understand complex data more easily.

Once the results were all collated into single csv file as described in the previous section, it was then imported into JMP. Figure 30 shows an instance of the imported data set. The scroll bars at the bottom and right of the screen shot indicate that not all rows and columns can be displayed simultaneously.

Identifier	ReserveRuleset	AdmissionControl/Ruleset	AggressiveCivs/Anger_Initial	AggressiveCivs/Anger_Dynamics	AggressiveCivs/RFA_Initial
1 IOE_A0	2	3	39	45	34
2 IOE_A1	5	3	43	46	9
3 IOE_A2	3	5	0	27	41
4 IOE_A3	4	5	30	37	44
5 IOE_A4	1	3	55	23	10
6 IOE_A5	5	3	70	1	40
7 IOE_A6	3	6	76	29	16
8 IOE_A7	4	5	89	6	34
9 IOE_A8	1	1	26	20	20
10 IOE_A9	6	1	22	27	12
11 IOE_A10	1	6	48	28	31
12 IOE_A11	6	6	25	38	14
13 IOE_A12	3	2	95	18	41
14 IOE_A13	5	2	92	35	9
15 IOE_A14	2	4	98	23	47
16 IOE_A15	5	5	98	3	17
17 IOE_A16	2	2	20	74	4
18 IOE_A17	6	3	27	78	42
19 IOE_A18	2	5	28	52	21
20 IOE_A19	4	6	38	75	13
21 IOE_A20	2	2	82	95	49
22 IOE_A21	4	2	65	92	38
23 IOE_A22	2	5	77	98	33
24 IOE_A23	5	4	97	98	19
25 IOE_A24	2	2	45	61	32
26 IOE_A25	6	1	46	57	15
27 IOE_A26	2	5	27	100	5
28 IOE_A27	6	6	37	70	16
29 IOE_A28	2	3	77	55	36
30 IOE_A29	4	3	99	70	48
31 IOE_A30	3	5	71	76	7
32 IOE_A31	4	4	94	89	13
33 IOE_A32	1	3	32	34	55

Figure 30 Importing Data into JMP.

Each row of data corresponds to one design point. Note that I0E_A identifies these as belonging to experiment A for the basecase NoLeader.

The modeling types tell each analysis platform how to analyze and graph the data. The following types are used in JMP [JMP Introductory Guide, version 5.1", 2003]:

Continuous

For continuous columns, which are essentially quantitative data (continuous- or integer-valued), the numeric value is used directly in the model. Most of the variables used are continuous, for example *NormalCivs/Fear_Initial* and *AggressiveCivs/Anger_Initial*.

Ordinal

An ordinal column can be either numeric or character and have either numbers or characters as values. The ordinal value is not used directly, but only as a name. However, ordinal variables have an implied ranking (such as 1, 2 and 3 corresponding to low, medium, and high values, respectively).

Nominal

For the nominal modeling type, the values are treated as unordered categories or names. The variables Rulesets and Leader fall into this category, since the numbering of Rulesets is purely arbitrary and so is the assignment of 0 to the case when there is no leader.

After the file is imported into JMP, there is a need to set some of the factors to the type "Nominal." The default type imported as "Continuous" will cause JMP to interpret the values in a wrong manner and result in undesirable analyses. Figure 31 shows how the Reserve/Ruleset modeling type can be set to Nominal.

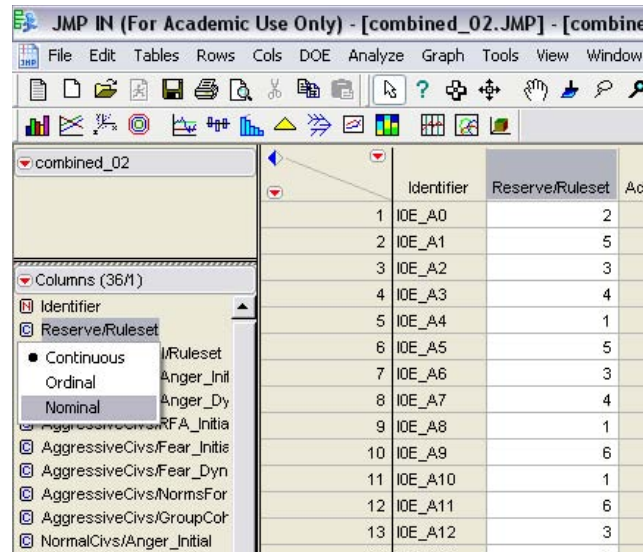


Figure 31 Modeling Types.

Now the data is ready for stepwise linear regression analysis. JMP provides excellent graphical user interfaces and easy-to-use functions that facilitate the following analysis steps:

- Select the response variables, i.e., the MOE.
- Select the regressor terms, including factorial up to degree 2, i.e., include all two-way interaction terms.
- Select the regressor terms, including polynomial up to degree 2, i.e., include all quadratic terms for main effect.
- Select stepwise and choose “Prob to Enter” and “Prob to Leave” values. Specifying a “Mixed” model will allow factors to enter and leave the model according to how their p-values compare to these criteria.
- Iterate through until model is deemed “satisfactory.” This may involve changing the “Prob to Enter” and “Prob to Leave” values to alter the number of terms in the resulting model.

- Select “Make Model” and associated model statistics will be available for further analysis.

Subscripted variables are used in the model equations to represent the factors. For ease of reference, variables z_1 to z_5 relate to Soldier Rulesets, x_1 to x_7 refer to factors for the non-pass-holders (AggressiveCivs), y_1 to y_9 refer to factors describing the pass-holders (Normal Civs), and v_1 to v_2 characterize the civilian leader.

2. Investigation of Aggregated Escalation

The interactions between warring groups or between civilians and peacekeeping forces can often lead to conflicts and escalation of the situation. There could be increased amount of threatening and aggressive acts, including verbal and physical attacks. Hence it is important to measure such interactions as an indicator of the level of escalation.

a. Entire Set of Scenarios

We begin by considering the aggregated escalation across the entire set of scenarios (Escalation_Combined_All). The first stepwise model produced a total of 24 terms, with $R^2 = 0.448$. After removing some terms, the model included an intercept, 5 main effect terms and another 5 interaction terms and the R^2 dropped to 0.370. Figure 32 shows these factors and the respective parameter estimates. Note that JMP automatically subtracts the average value from a continuous factor if it appears in a quadratic or interaction term. This insures that adding quadratic or interaction terms to the model does not result in multicollinearity among the model terms.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	-12.96856	12.12563	-1.07	0.2852
Reserve/Ruleset{6&1&2&5&3-4}	-47.2218	4.730957	-9.98	<.0001
AggressiveCivs/Anger_Initial	0.4357764	0.12201	3.57	0.0004
AggressiveCivs/RFA_Initial	1.2158236	0.129351	9.40	<.0001
AggressiveCivs/GroupCohesiveness	0.4324957	0.122542	3.53	0.0004
Leader[0]	19.980814	3.745455	5.33	<.0001
(Reserve/Ruleset{6&1&2&5&3-4}-0.5969)*(AggressiveCivs/Anger_Initial-50.0155)	-0.805474	0.146115	-5.51	<.0001
(Reserve/Ruleset{6&1&2&5&3-4}-0.5969)*(AggressiveCivs/RFA_Initial-50.0155)	-1.219383	0.15971	-7.63	<.0001
(Reserve/Ruleset{6&1&2&5&3-4}-0.5969)*(AggressiveCivs/GroupCohesiveness-50.0155)	-0.96045	0.166635	-5.76	<.0001
(Reserve/Ruleset{6&1&2&5&3-4}-0.5969)*Leader[0]	-50.23643	4.672878	-10.75	<.0001
(AggressiveCivs/RFA_Initial-50.0155)*Leader[0]	0.8478401	0.128885	6.58	<.0001

Figure 32 Parameter Estimates for Escalation_Combined_All Model.

The p-values were all relatively low, indicating that further removal of any terms will cause the R^2 to drop by a significant amount. The two terms that stood out were Reserve/Ruleset{6&1&2&5&3-4} and Leader[0]. In the setup of experiments, the Reserve Soldiers have Rulesets ranging from 1 to 6 and the term Reserve/Ruleset{6&1&2&5&3-4} grouped Rulesets 1 through 5 as having similar effects that were different from Ruleset 4. In JMP, it automatically coded a “1” whenever Reserve Soldiers Ruleset is 1 through 5 and a “-1” was used for Ruleset 4. Alternatively, the user may manually code the levels, as in the term Leader[0], which had been coded before the experiment with “0” representing NoLeader and “1” indicating the presence of a leader.

The model for aggregated escalation may then be represented by:

$$\begin{aligned} \hat{esc}(all) = & -12.969 - 47.222z_1 + 0.436x_1 + 1.216x_3 + 0.432x_7 + 19.981v_1 \\ & -0.805(z_1 - 0.597)(x_1 - 50.0155) - 1.219(z_1 - 0.597)(x_3 - 50.0155) \\ & -0.960(z_1 - 0.597)(x_7 - 50.0155) - 50.236(z_1 - 0.597)(v_1) + 0.848(x_3 - 50.0155)(v_1) \end{aligned}$$

where: $z_1 = Reserve/Rule\{6\&1\&2\&5\&3-4\}$
 $x_1 = AggressiveCivs/Anger_Initial$
 $x_3 = AggressiveCivs/RFA_Initial$
 $x_7 = AggressiveCivs/GroupCohesiveness$
 $v_1 = Leader[0]$

The coefficient of *Reserve/Rule{6&1&2&5&3-4}* was -47.222, indicating that whenever Reserve Soldiers Ruleset was anything from 1 through 5, the escalation was increased by -47.222 units, which was good since we wanted escalation to be low. On the other hand, if Reserve Soldiers Ruleset was 4, we would subtract -47.222 from the escalation, which in effect increased the escalation. Hence we see that the Gandhi strategy (Ruleset 4) is not always the best choice.

The above discussion considers only the main effect of the Rulesets, but this factor also appears in four interaction terms. JMP provides a Prediction Profiler function which displays prediction traces, which are the predicted responses as one variable is changed while the others are held constant at their current values [JMP Introductory Guide, version 5.1", 2003]. From the Prediction Profiler diagrams shown in Figure 33 and Figure 34 it is noted that in the absence of a civilian leader (Leader=0), the average escalation rose from 43.777 to 238.294, when the Reserve Soldiers Ruleset is changed from any other Ruleset to 4. Furthermore, we see that when there is no leader

and Ruleset is 4, the *AggressiveCivs/Anger_Initial*, *AggressiveCivs/RFA_Initial* and *AggressiveCivs/GroupCohesiveness* all have larger impacts on the escalation, as evident from the steeper slopes in Figure 34

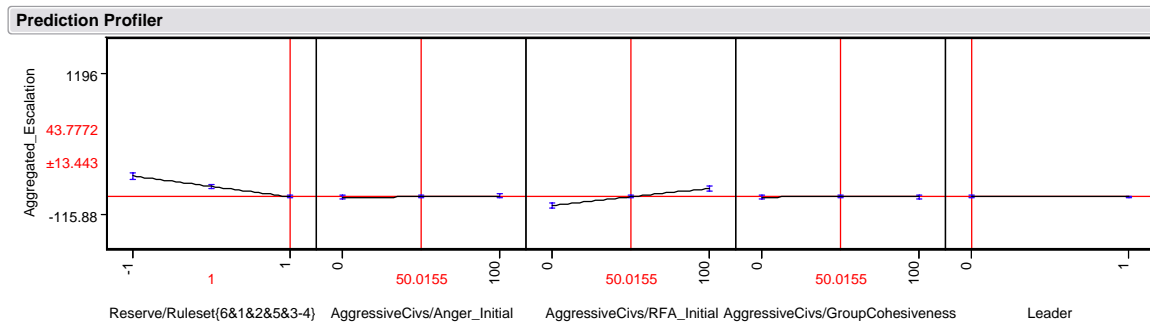


Figure 33 Escalation_Combined_All - Absence of Leader and Ruleset ≠ 4.

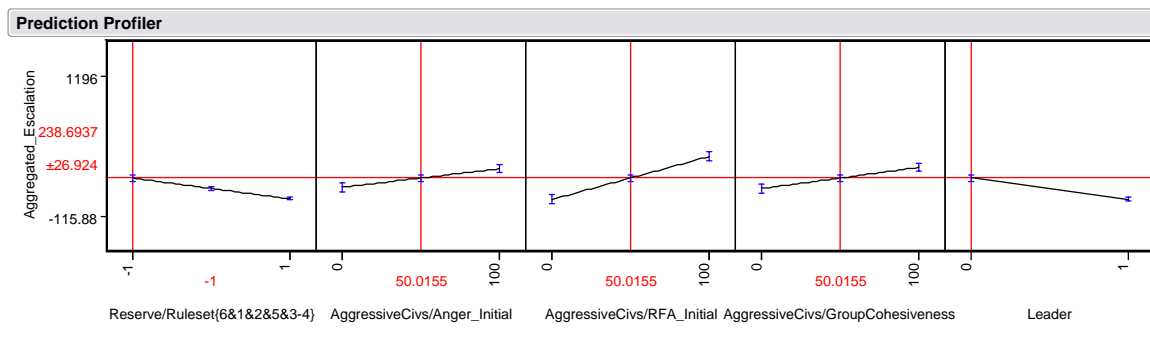


Figure 34 Escalation_Combined_All: Absence of Leader and Ruleset = 4.

On the other hand, when a civilian leader was included in the scenario (Leader=1), we observed from Figure 35 and Figure 36 that the Reserve Soldiers Ruleset did not have as great an impact on the escalation as before, since the average Aggregated_Escalation now varied between 44.315 to 38.260. However, the trend remained consistent with the previous case: when the soldiers use Ruleset 4 (Gandhi strategy), the *AggressiveCivs/Anger_Initial*, *AggressiveCivs/RFA_Initial* and *AggressiveCivs/GroupCohesiveness* continue to have larger impacts on the escalation.

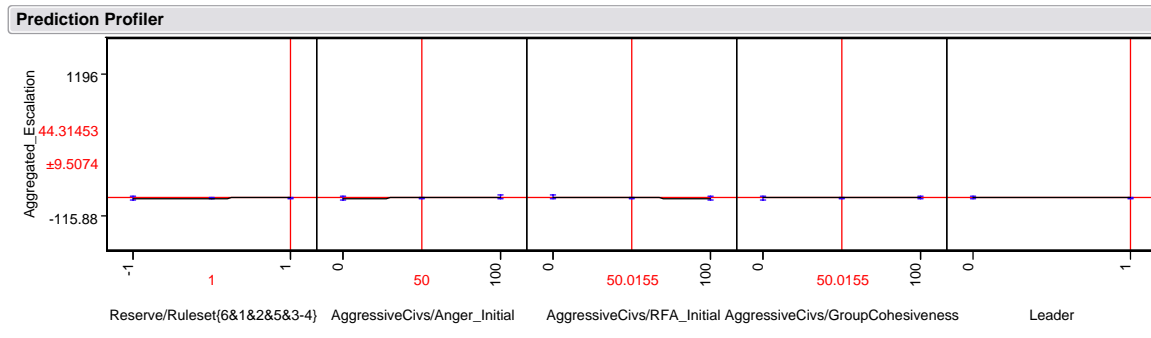


Figure 35 Escalation_Combined_All - Presence of Leader and Ruleset ≠ 4.

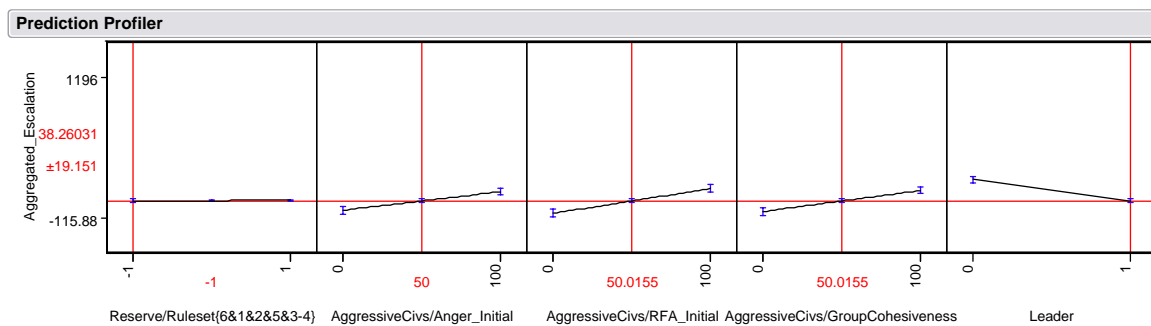


Figure 36 Escalation_Combined_All: Presence of Leader and Ruleset = 4.

Because there were such strong differences between the two situations, we separated the data set to distinguish those in the presence of a civilian leader (516 design points) from those without a leader (258 design points). When we look at all the data points as a single data set, the model is usually simpler to explain and it provides more degree of freedom, more so in the event that the data set is small. On the other hand, by subsetting the data according to presence or absence of a civilian leader, we are able to examine the data in more detail, discovering factor effects that might otherwise be masked by others in the single data set analysis.

b. Civilian Leader Present

In the case of presence of a civilian leader, half of the design points had the LeaderCooperativeness set to 40 (out of 100), representing a leader who

was not so cooperative with the soldiers. The other half had the LeaderCooperativeness set to 60, indicating a slightly more cooperative leader.

The same stepwise regression technique was used as before. The final model contained nine terms—eight main effects and one interaction term. Figure 37 provides details.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	22.287765	8.756386	2.55	0.0112
Reserve/Ruleset{6-1&5&2&3&4}	-12.61005	3.428447	-3.68	0.0003
Reserve/Ruleset{1&5&2&3-4}	-7.671266	2.621231	-2.93	0.0036
AdmissionControl/Ruleset{5&3&6&1&4-2}	-15.63359	2.664493	-5.87	<.0001
AggressiveCivs/Anger_Initial	0.198949	0.069485	2.86	0.0044
AggressiveCivs/RFA_Initial	0.2391012	0.069228	3.45	0.0006
NormalCivs/RFA_Initial	0.1957328	0.069143	2.83	0.0048
NormalCivs/Fear_Initial	-0.23285	0.069636	-3.34	0.0009
NormalCivs/ElectionMotive	0.1953489	0.069246	2.82	0.0050
(Reserve/Ruleset{1&5&2&3-4})-0.49612)*(AdmissionControl/Ruleset{5&3&6&1&4-2})-0.5969	27.436609	3.706318	7.40	<.0001

Figure 37 Parameter Estimates for Escalation_Leader Model.

The model for Escalation_Leader may then be represented by:

$$\hat{e}sc(Leader) = 22.288 - 12.610z_2 - 7.671z_3 - 15.634z_5 + 0.199x_1 + 0.239x_3 + 0.196y_3 - 0.233y_4 + 0.195y_9 + 27.437(z_3 - 0.496)(z_5 - 0.597)$$

where: $z_2 = Reserve/Ruleset\{6-1\&5\&2\&3\&4\}$

$z_3 = Reserve/Ruleset\{1\&5\&2\&3-4\}$

$z_5 = AdmissionControl/Ruleset\{5\&3\&6\&1\&4-2\}$

$x_1 = AggressiveCivs/Anger_Initial$

$x_3 = AggressiveCivs/RFA_Initial$

$y_3 = NormalCivs/RFA_Initial$

$y_4 = NormalCivs/Fear_Initial$

$y_9 = NormalCivs/ElectionMotive$

It is interesting to note that Reserve Ruleset 6 is different (lower escalation) from the rest. Once again, Ruleset 4 is the worst choice. Another observation is that the NormalCivs characteristics now appear in the model, while none of these are significant in the previous model. Another observation is that the escalation never exceed 500, indicating that all cases of extremely high escalation (reaching a maximum of 1196) occurred in those experiments where no leader was present. Yet another point to note is that the LeaderCooperativeness did not show up in this single model. One of the reason may be the difference of 40 (for LessCooperativeLeader) to 60 (MoreCooperativeLeader) is not large enough for the effects to show up. It also highlights the difficulty in this aspect of modeling, as well as real-life operations, where the cooperativeness of the civilian leader needs to be assessed and given an appropriate value.

The R^2 of 0.230366 may be low, but the Root Mean Square Error of 45.64 is better than the 98.24 for the combined model. This means that the residuals are closer to the fitted regression equation than in the combined model.

c. Civilian Leader Absent

The initial model fitted to the data points collected from those experiments without the leader yield a 19-term model with a surprisingly high R^2 of 0.699. However, a model with too many terms was not easily interpreted. After further fine-tuning of the model, we eventually selected a model with six main effects and five interaction terms, yielding an R^2 of 0.623. No quadratic terms were statistically significant. Figure 38 contains the table of model coefficients.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	-80.24178	32.06925	-2.50	0.0130
Reserve/Ruleset{6&2&1&5&3-4}	-85.6149	9.779229	-8.75	<.0001
AggressiveCivs/Anger_Initial	0.8467543	0.267161	3.17	0.0017
AggressiveCivs/Anger_Dynamics	-0.72164	0.267429	-2.70	0.0074
AggressiveCivs/RFA_Initial	2.1571054	0.267494	8.06	<.0001
AggressiveCivs/GroupCohesiveness	0.8768656	0.268621	3.26	0.0013
NormalCivs/RFA_Initial	1.0255747	0.266369	3.85	0.0002
(Reserve/Ruleset{6&2&1&5&3-4}-0.5969)*(AggressiveCivs/Anger_Initial-50.0155)	-1.68755	0.320248	-5.27	<.0001
(Reserve/Ruleset{6&2&1&5&3-4}-0.5969)*(AggressiveCivs/Anger_Dynamics-50.0155)	1.5258151	0.357775	4.26	<.0001
(Reserve/Ruleset{6&2&1&5&3-4}-0.5969)*(AggressiveCivs/RFA_Initial-50.0155)	-3.475273	0.351352	-9.89	<.0001
(Reserve/Ruleset{6&2&1&5&3-4}-0.5969)*(AggressiveCivs/GroupCohesiveness-50.0155)	-1.883814	0.366315	-5.14	<.0001
(Reserve/Ruleset{6&2&1&5&3-4}-0.5969)*(NormalCivs/RFA_Initial-50.0155)	-1.431199	0.338914	-4.22	<.0001

Figure 38 Parameter Estimates for Escalation_NoLeader Model.

The model for Escalation_NoLeader may then be represented by:

$$\begin{aligned} \hat{esc}(NoLeader) = & -80.242 - 85.615z_1 + 0.847x_1 - 0.722x_2 + 2.157x_3 + 0.877x_7 + 1.026y_3 \\ & - 1.688(z_1 - 0.597)(x_1 - 50.0155) + 1.526(z_1 - 0.597)(x_2 - 50.0155) \\ & - 3.475(z_1 - 0.597)(x_3 - 50.0155) - 1.884(z_1 - 0.597)(x_7 - 50.0155) \\ & - 1.431(z_1 - 0.597)(y_3 - 50.0155) \end{aligned}$$

where:

$$\begin{aligned} z_1 &= Reserve/Ruleset\{6\&1\&2\&5\&3-4\} \\ x_1 &= AggressiveCivs/Anger_Initial \\ x_2 &= AggressiveCivs/Anger_Dynamics \\ x_3 &= AggressiveCivs/RFA_Initial \\ x_7 &= AggressiveCivs/GroupCohesiveness \\ y_3 &= NormalCivs/RFA_Initial \end{aligned}$$

We noted that all the interaction terms involved the *Reserve/Ruleset{6&2&1&5&3-4}* factor, indicating that the Gandhi strategy had significant impact on the escalation MOE.

With many interaction terms, it can be difficult to determine the overall impact of a factor by looking only at the regression coefficients. Figure 39 shows that when the Ruleset is anything other than 4, all the other five main effect terms have little or negligible effect on the escalation, as evident from the

relatively flat slopes in the Prediction Profiler diagrams. One way of looking at this is that other than the Gandhi strategy, all other Rulesets seem pretty robust in this situation, resulting in roughly the same amount of escalation over a wide range of civilian population combinations.

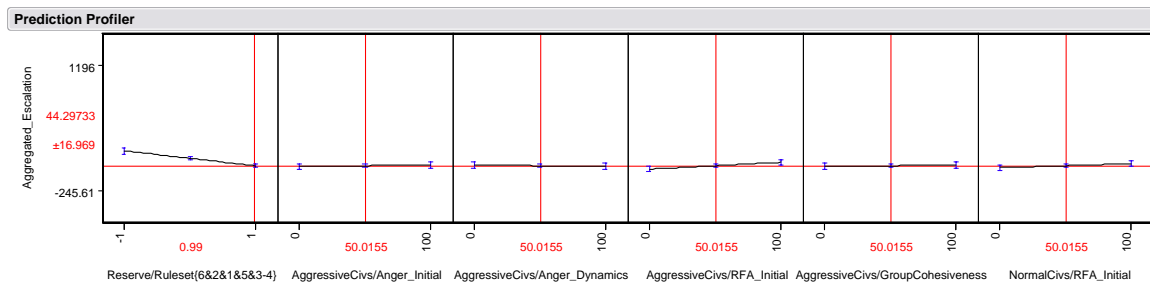


Figure 39 Escalation_NoLeader: Absence of Leader and Ruleset ≠ 4.

On the other hand, Figure 40 shows that when the Reserve/Ruleset is 4, the average escalation has a mean of 213.815, when all the other main effect terms are kept at their mean values. This is substantially higher than the average of 44.297 shown in Figure 39 for all other Rulesets.

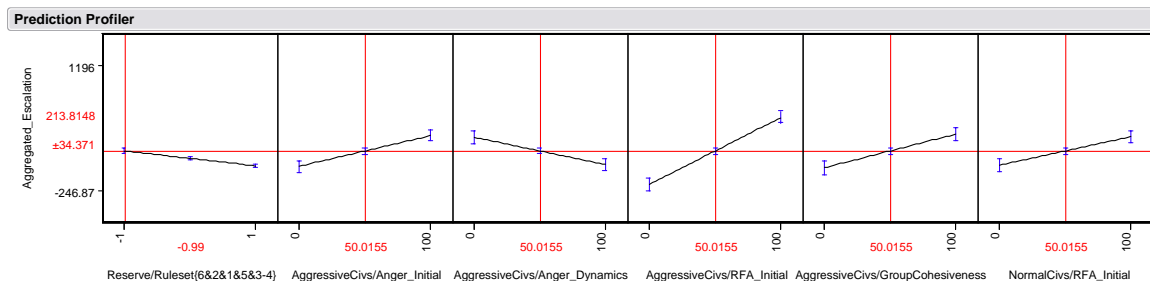


Figure 40 Escalation_NoLeader: Absence of Leader and Ruleset = 4.

Another critical observation was that the slopes in the Prediction Profiler were much steeper now, especially for the *AggressiveCivs/RFA_Initial* factor. One possible interpretation for the decision-maker is that in determining the rules of engagement for the soldiers, it is important to assess the civilians'

readiness for aggression. If the population has a low readiness for aggression factor, the Gandhi strategy may produce a good payoff in terms of bringing the escalation to a low level. However, if the readiness for aggression is high, the Gandhi strategy may end up causing extremely high escalation.

3. Investigation of the Number Crossing the Checkpoint

Recall in Chapter III that we used the “Election” motivation as a surrogate for the civilian’s desire to cross the checkpoint. One of the MOEs provided by PAX is the number of “elections” at the end of the simulation run. We now analyze this MOE in a similar manner to the analysis of escalation: we use stepwise regression and then fine-tune the model to balance its simplicity and explanatory power.

a. Entire Set of Scenarios

When looking at Elections as the MOE, the model using the complete data set yielded a R^2 of 0.390. Five main effect terms and two interaction terms appear in the model. Figure 41 shows the parameter estimates and p-values.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	1.4952288	0.632776	2.36	0.0184
NormalCivs/Anger_Initial	-0.056926	0.005492	-10.36	<.0001
NormalCivs/Anger_Dynamics	0.0429795	0.005492	7.83	<.0001
NormalCivs/Fear_Initial	0.0217147	0.005492	3.95	<.0001
NormalCivs/Fear_Dynamics	-0.02391	0.005492	-4.35	<.0001
NormalCivs/ElectionMotive	0.087048	0.005492	15.85	<.0001
(NormalCivs/Anger_Dynamics-50.0155)*(NormalCivs/Fear_Initial-50.0155)	0.0009072	0.000194	4.69	<.0001
(NormalCivs/Anger_Dynamics-50.0155)*(NormalCivs/Fear_Dynamics-50.0155)	-0.000839	0.000199	-4.22	<.0001

Figure 41 Parameter Estimates for Elections_Combined_All Model.

The model for Elections_Combined_All may then be represented by:

$$\begin{aligned} elections(all) = & 1.495 - 0.0569y_1 + 0.0430y_2 - 0.0217y_4 - 0.0239y_5 + 0.0870y_9 \\ & + 0.000907(y_2 - 50.0155)(y_4 - 50.0155) - 0.000839(y_2 - 50.0155)(y_5 - 50.0155) \end{aligned}$$

where: $y_1 = NormalCivs/Anger_Initial$
 $y_2 = NormalCivs/Anger_Dynamics$
 $y_4 = NormalCivs/Fear_Initial$
 $y_5 = NormalCivs/Fear_Dynamics$
 $y_9 = NormalCivs/ElectionMotive$

The key observation here was that only those factors affecting the pass-holders (NormalCivs) characteristics were significant in determining the number of people who achieved their goals. Not surprising, the *NormalCivs/ElectionMotive* appeared to have most positive impact in the number of elections since a higher value would indicate the civilians' propensity to move across the checkpoint and approach the polling station. On the other hand, the *NormalCivs/Anger_Initial* had the largest negative impact since a higher value would make "Anger" the leading motive and the civilians would be more prone to threaten or attack soldiers and other civilians than to go for voting.

From the interaction plots in Figure 42 note that when *NormalCivs/Anger_Dynamics* was high and coupled with an increasing *NormalCivs/Fear_Initial*, it had a positive impact (larger number of elections) as more civilians got across the checkpoint and achieved their objectives. This was initially counter-intuitive. A run of the simulation with such a setting revealed that the NormalCivs with higher fear would initially tend to seek shelter or refuge first

and hence avoided the threats or attacks from the AggressiveCivs group. When the AggressiveCivs were “dealt with” by the soldiers, the NormalCivs would subsequently get out of the refuge and began to cross the checkpoint and go to the polling station.

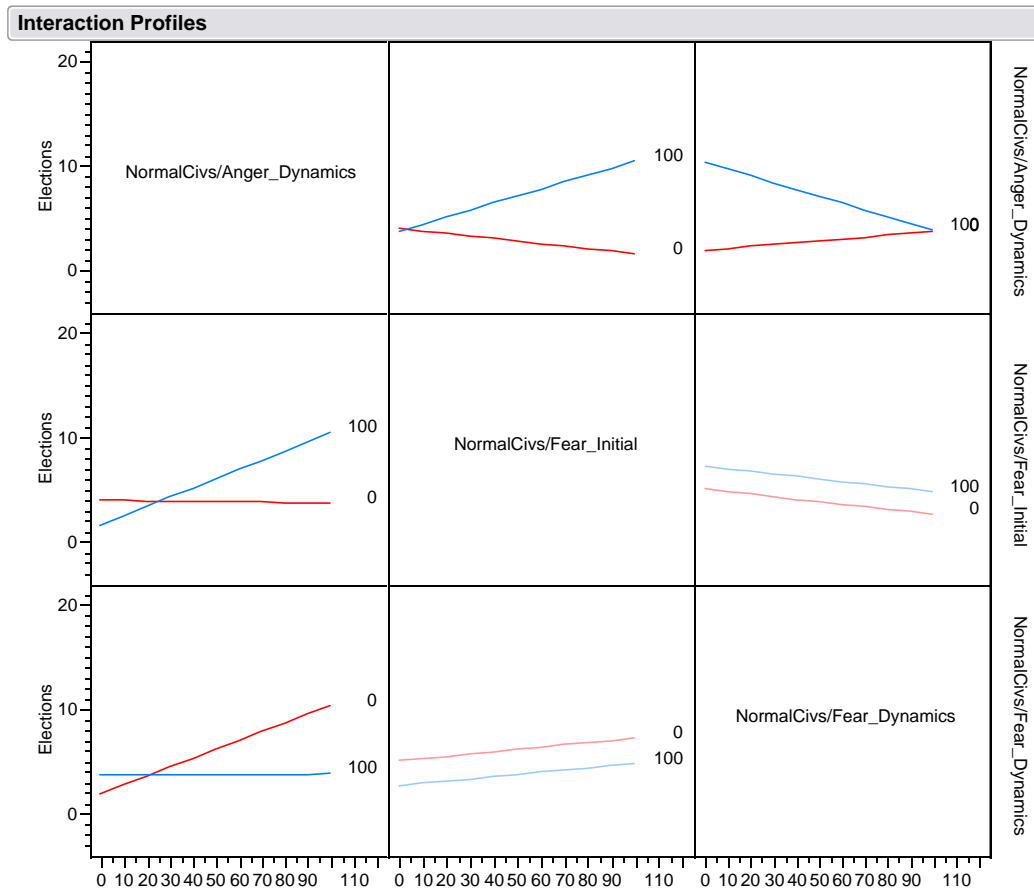


Figure 42 Interaction plots for Elections_Combined_All Model.

b. Civilian Leader Present

Despite the fact that presence/absence of a leader did not show up as a significant factor for the Elections MOE, we performed analyses with the two subsets to see if similar results were achieved.

The $R^2 = 0.330$ for the case with the leader. Figure 43 provides the parameter estimates and p-values. Three of the factors (*NormalCivs/Anger_Initial*, *NormalCivs/Anger_Dynamics*, and *NormalCivs/ElectionMotive*) also appeared in the combined model, but several terms differ.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	2.3802715	1.247232	1.91	0.0569
AggressiveCivs/GroupCohesiveness	-0.021545	0.006973	-3.09	0.0021
NormalCivs/Anger_Initial	-0.045942	0.006973	-6.59	<.0001
NormalCivs/Anger_Dynamics	0.039195	0.006973	5.62	<.0001
NormalCivs/ElectionMotive	0.0788111	0.006973	11.30	<.0001
LeaderCooperativeness	0.0031008	0.020284	0.15	0.8786
(NormalCivs/Anger_Initial-50.0155)*(LeaderCooperativeness-50)	-0.003398	0.000697	-4.87	<.0001
(NormalCivs/ElectionMotive-50.0155)*(LeaderCooperativeness-50)	0.0027438	0.000697	3.93	<.0001

Figure 43 Parameter Estimates for Elections_Leader Model.

The model for Elections_Leader may then be represented by:

$$\begin{aligned} elections(Leader) = & 2.380 - 0.0215x_7 - 0.0459y_1 + 0.0392y_2 + 0.0788y_9 + 0.00310v_2 \\ & - 0.00340(y_1 - 50.0155)(v_2 - 50) + 0.00274(y_9 - 50.0155)(v_2 - 50) \end{aligned}$$

where: $x_7 = AggressiveCivs/GroupCohesiveness$

$y_1 = NormalCivs/Anger_Initial$

$y_2 = NormalCivs/Anger_Dynamics$

$y_9 = NormalCivs/ElectionMotive$

$v_2 = LeaderCooperativeness$

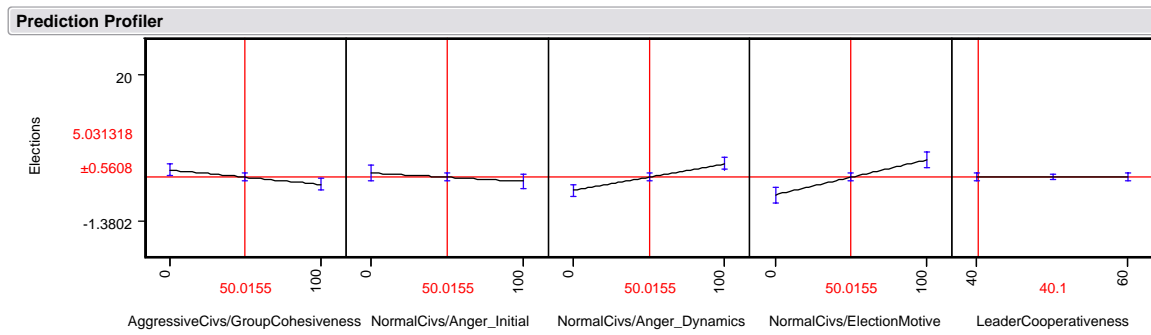


Figure 44 Elections_Leader: LeaderCooperativeness = 40

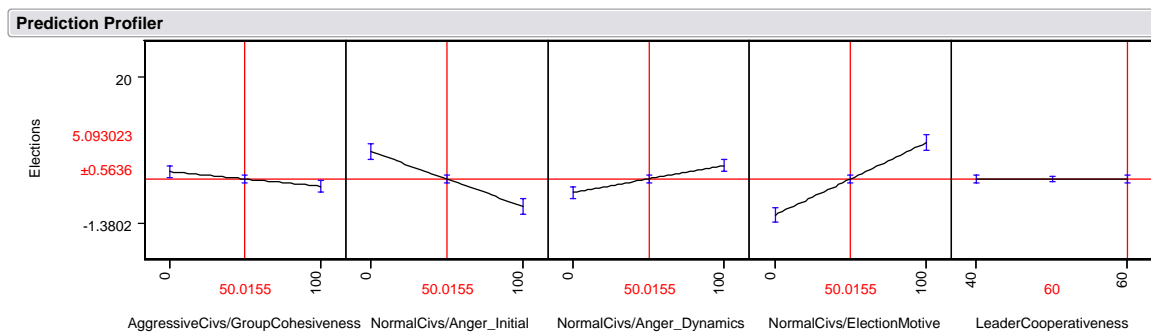


Figure 45 Elections_Leader: LeaderCooperativeness = 60

The Prediction Profiler plots shown in Figure 44 and Figure 45 suggest that when the AggressiveCivs group had a leader that was more cooperative, the effects of *NormalCivs/ElectionMotive* and *NormalCivs/Anger_Initial* could be felt even more strongly.

c. **Civilian Leader Absent**

In the event that there was no leader, the final model had $R^2 = 0.572$ and the same five main effect terms as the combined model. It also had an interaction term, however, involving the *NormalCivs/Fear_Dynamics* and *NormalCivs/ElectionMotive*.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	1.3077399	0.948977	1.38	0.1694
NormalCivs/Anger_Initial	-0.078768	0.008237	-9.56	<.0001
NormalCivs/Anger_Dynamics	0.0504142	0.008237	6.12	<.0001
NormalCivs/Fear_Initial	0.0348111	0.008237	4.23	<.0001
NormalCivs/Fear_Dynamics	-0.036139	0.008237	-4.39	<.0001
NormalCivs/ElectionMotive	0.1034173	0.008237	12.56	<.0001
(NormalCivs/Fear_Dynamics-50.0155)*(NormalCivs/ElectionMotive-50.0155)	-0.001062	0.000292	-3.63	0.0003

Figure 46 Parameter Estimates for Elections_NoLeader Model.

The model for Elections_NoLeader may then be represented by:

$$\begin{aligned}
 elections(NoLeader) = & 1.308 - 0.0788y_1 + 0.0504y_2 + 0.0348y_4 - 0.0361y_5 \\
 & + 0.103y_9 - 0.00106(y_5 - 50.0155)(y_9 - 50.0155)
 \end{aligned}$$

where:

$$y_1 = NormalCivs/Anger_Initial$$

$$y_2 = NormalCivs/Anger_Dynamics$$

$$y_4 = NormalCivs/Fear_Initial$$

$$y_5 = NormalCivs/Fear_Dynamics$$

$$y_9 = NormalCivs/ElectionMotive$$

From the Prediction Profiler plots, we saw in Figure 47 that when *NormalCivs/ElectionMotive* was lower than 15, increasing the *NormalCivs/Fear_Dynamics* had a small but positive impact on the Elections MOE. However, in Figure 48 as the *NormalCivs/ElectionMotive* got higher, the *NormalCivs/Fear_Dynamics* now had a significant but negative impact instead.

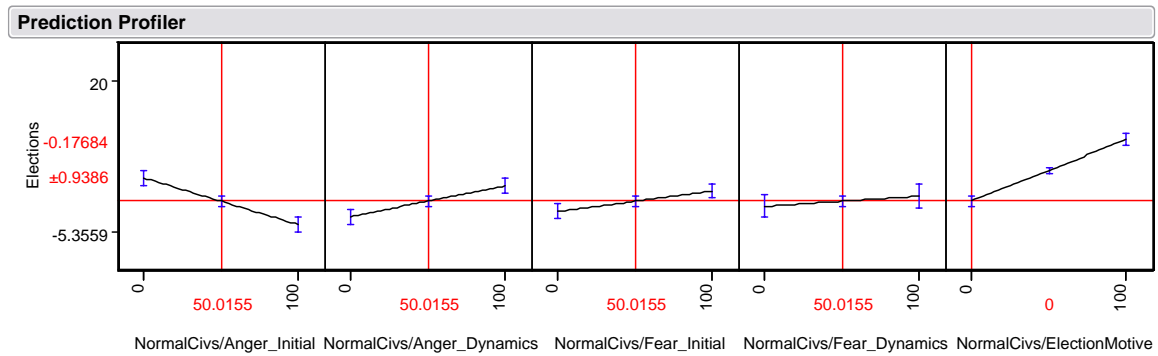


Figure 47 Low NormalCivs/ElectionMotive.

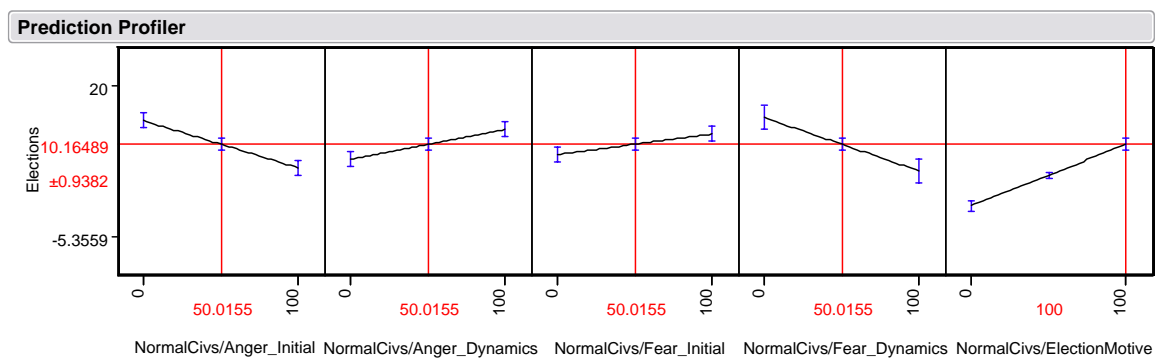


Figure 48 High NormalCivs/ElectionMotive.

4. Investigation of Final Average Civilian Fear

In peace support operations, it is important that a mission be executed with minimum use of force. A fearful population at the end of the operation might even increase resentment and would not benefit future peacekeeping operations.

a. Entire Set of Scenarios

When looking at TEnd_Civilians_Average_Fear as the MOE, the model using the complete data set yielded $R^2 = 0.325$. Seven main effect terms and three interaction terms were present, along with one quadratic term. Figure 49 provides the Actual by Predicted plot, along with the parameter estimates and p-values. Note that the large variability meant that the model did not get a good fit. One of the possible reasons could be that this MOE did not distinguish the fear experienced by the different civilian groups, which could be at very different

levels under various circumstances. When these fear levels are aggregated into a single MOE, it would be hard to find a simple model to explain the behavior.

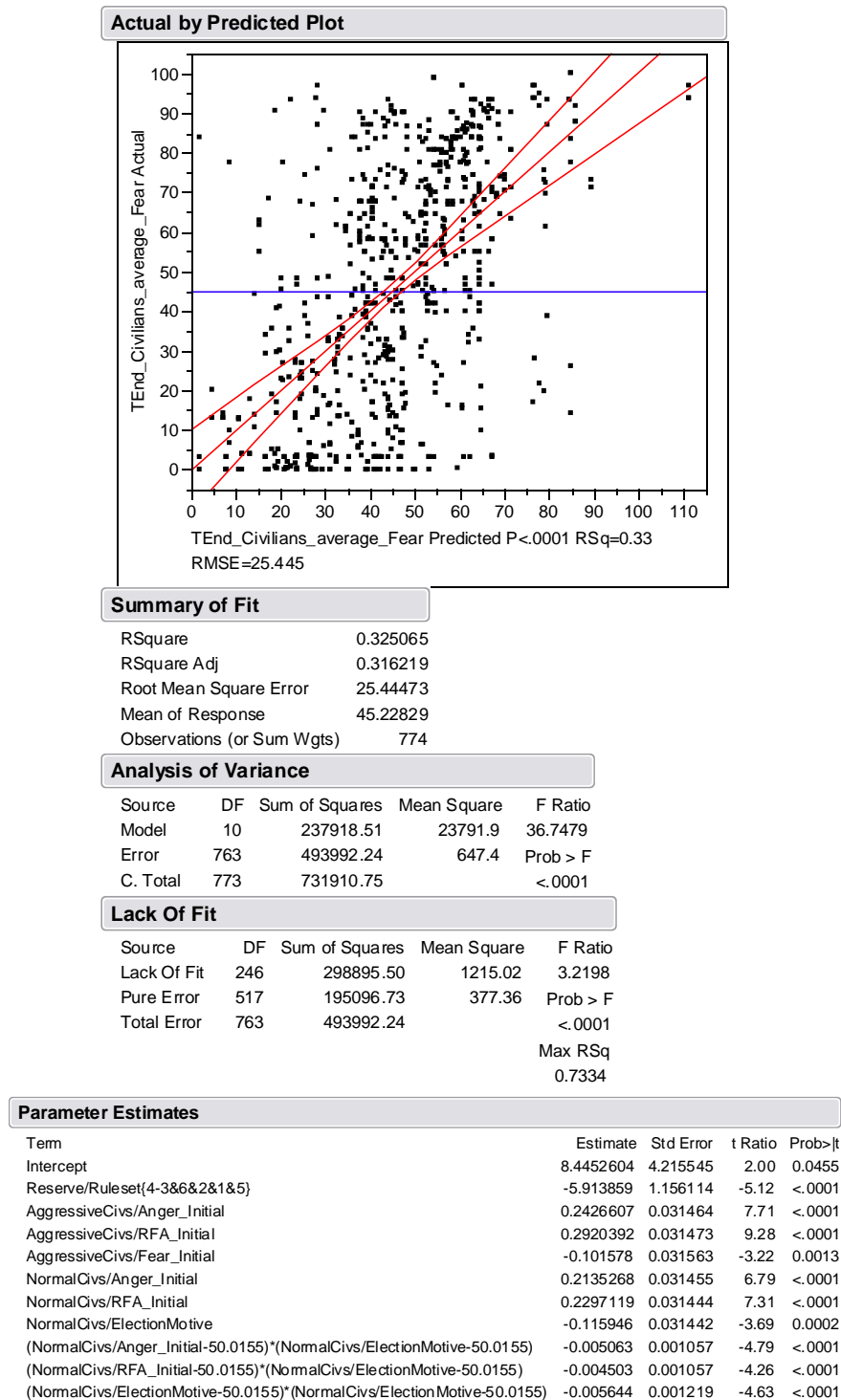


Figure 49 Parameter Estimates for TEnd_Civilians_Average_Fear_Combined_All Model.

The model for TEnd_Civilians_Average_Fear_Combined_All may then be represented by:

$$\begin{aligned} \hat{fear}(all) = & 8.445 - 5.914(-z_1) + 0.243x_1 + 0.292x_3 - 0.102x_4 + 0.214y_1 + 0.230y_4 - 0.116y_9 \\ & - 0.00506(y_1 - 50.0155)(y_9 - 50.0155) - 0.00450(y_3 - 50.0155)(y_9 - 50.0155) \\ & - 0.00564(y_9 - 50.0155)(y_9 - 50.0155) \end{aligned}$$

where:

- $z_1 = \text{Reserve/Ruleset}\{6\&1\&2\&5\&3-4\}$
- $-z_1 = \text{Reserve/Ruleset}\{4-3\&6\&2\&1\&5\}$
- $x_1 = \text{AggressiveCivs/Anger_Initial}$
- $x_3 = \text{AggressiveCivs/RFA_Initial}$
- $x_4 = \text{AggressiveCivs/Fear_Initial}$
- $y_1 = \text{NormalCivs/Anger_Initial}$
- $y_3 = \text{NormalCivs/RFA_Initial}$
- $y_9 = \text{NormalCivs/ElectionMotive}$

The interaction plots corresponding to this model are provided in Figure 50 . We see that when *NormalCivs/ElectionMotive* is high (blue line labeled as 100), *NormalCivs/Anger_Initial* and *NormalCivs/RFA_Initial* have little impact on this MOE, indicated by the relatively flat slopes. On the other hand, when *NormalCivs/ElectionMotive* is low (red line labeled as 0), *NormalCivs/Anger_Initial* and *NormalCivs/RFA_Initial* now have negative impact on the final civilian average fear, as can be observed from the positive slopes. The curved lines show the quadratic effects of the *NormalCivs/ElectionMotive*.

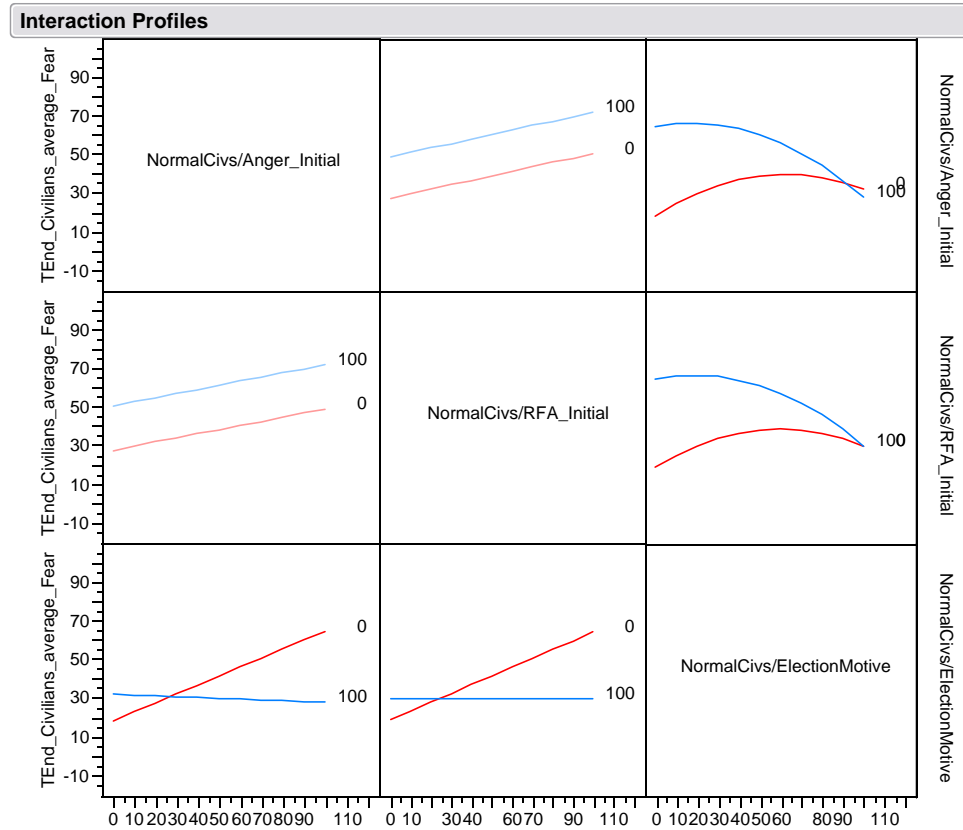


Figure 50 Interaction Plots for TEnd_Civilians_Average_Fear_Combined_All Model.

b. Civilian Leader Present

Again, for the sake of discussion and comparison with models constructed for other MOEs, separate analyses were conducted for the data subsets of with and without a civilian leader. In the case where a leader was present, the final model reported $R^2 = 0.228$, including six main effect terms and one interaction term.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	9.8171772	4.733528	2.07	0.0386
Reserve/Ruleset{4&3&6-2&1&5}	-5.408383	1.18958	-4.55	<.0001
AggressiveCivs/Anger_Initial	0.2304923	0.040911	5.63	<.0001
AggressiveCivs/RFA_Initial	0.2556685	0.040863	6.26	<.0001
AggressiveCivs/Fear_Initial	-0.109874	0.041013	-2.68	0.0076
NormalCivs/Anger_Initial	0.1422318	0.040868	3.48	0.0005
NormalCivs/RFA_Initial	0.2021329	0.040814	4.95	<.0001
(Reserve/Ruleset{4&3&6-2&1&5}+0.00775)*(AggressiveCivs/Fear_Initial-50.0155)	0.1552252	0.041146	3.77	0.0002

Figure 51 Parameter Estimates for TEnd_Civilians_Average_Fear_Leader Model.

The model for TEnd_Civilians_Average_Fear_Leader may then be represented by:

$$\hat{fe}(Leader) = 9.8171772 - 5.408383z_4 + 0.2304923x_1 + 0.2556685x_3 - 0.109874x_4 + 0.1422318y_1 + 0.2021329y_3 + 0.1552252(z_4 + 0.00775)(x_4 - 50.0155)$$

where: $z_4 = Reserve/Ruleset\{4\&3\&6-2\&1\&5\}$

$x_1 = AggressiveCivs/Anger_Initial$

$x_3 = AggressiveCivs/RFA_Initial$

$x_4 = AggressiveCivs/Fear_Initial$

$y_1 = NormalCivs/Anger_Initial$

$y_3 = NormalCivs/RFA_Initial$

It was interesting to note that the Reserve/Ruleset was split into two groups. Rulesets 3,4 and 6 had a positive impact (lower fear) than Rulesets 1 and 2, while Ruleset 5 had a negative impact. However, it was difficult to comprehend how Rulesets such as Gandhi (Ruleset 4, always pacify) and Zero Tolerance (Ruleset 6, always defend) could produce similar effects when others are kept constant. One of the possible reasons could be due to the aggregation

of the MOE across different civilian groups. For example, an average fear of 50 for the two civilian groups could either be a combination of extreme highs and lows, or simply a case of fair contribution of the two groups. Hence, by aggregating the MOE, such distinction could not be easily identified.

c. *Civilian Leader Absent*

In the case when there was no leader, the model for the final average civilian fear yielded a R^2 of 0.435. Reserve/Ruleset 4 again stood out from the rest, resulting in lowering the average fear by approximately 17 units, on a scale of 0 to 100.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	-12.24951	6.05562	-2.02	0.0442
Reserve/Ruleset{4-3&6&5&1&2}	-8.463273	1.865141	-4.54	<.0001
AggressiveCivs/Anger_Initial	0.2505671	0.051263	4.89	<.0001
AggressiveCivs/RFA_Initial	0.3618132	0.051278	7.06	<.0001
NormalCivs/Anger_Initial	0.3377282	0.051249	6.59	<.0001
NormalCivs/RFA_Initial	0.2769415	0.051232	5.41	<.0001
NormalCivs/ElectionMotive	-0.199137	0.051228	-3.89	0.0001
(NormalCivs/Anger_Initial-50.0155)*(NormalCivs/ElectionMotive-50.0155)	-0.005891	0.001716	-3.43	0.0007

Figure 52 Parameter estimates for TEnd_Civilians_Average_Fear_NoLeader Model.

The model for TEnd_Civilians_Average_Fear_NoLeader may then be represented by:

$$\hat{fear}(NoLeader) = -12.250 - 8.463(-z_1) + 0.251x_1 + 0.362x_3 + 0.338y_1 + 0.277y_3 - 0.199y_9 - 0.00589(-z_1 - 50.0155)(y_9 - 50.0155)$$

where: $z_1 = Reserve/Ruleset\{6\&1\&2\&5\&3-4\}$

$-z_1 = Reserve/Ruleset\{4-3\&6\&2\&1\&5\}$

$x_1 = AggressiveCivs/Anger_Initial$

$x_3 = AggressiveCivs/RFA_Initial$

$$y_1 = \text{NormalCivs}/\text{Anger_Initial}$$

$$y_3 = \text{NormalCivs}/\text{RFA_Initial}$$

$$y_9 = \text{NormalCivs}/\text{ElectionMotive}$$

From the interaction plots below, it was noted that at low values of *NormalCivs/ElectionMotive*, the *NormalCivs/Anger_Initial* had a great impact on the *TEnd_Civilian_Average_Fear*. Simulation results showed that at when the civilians had a low *ElectionMotive*, the leading motive could then be Fear or Anger. This could lead to “clashes” with soldiers, thus resulting in higher average fear.

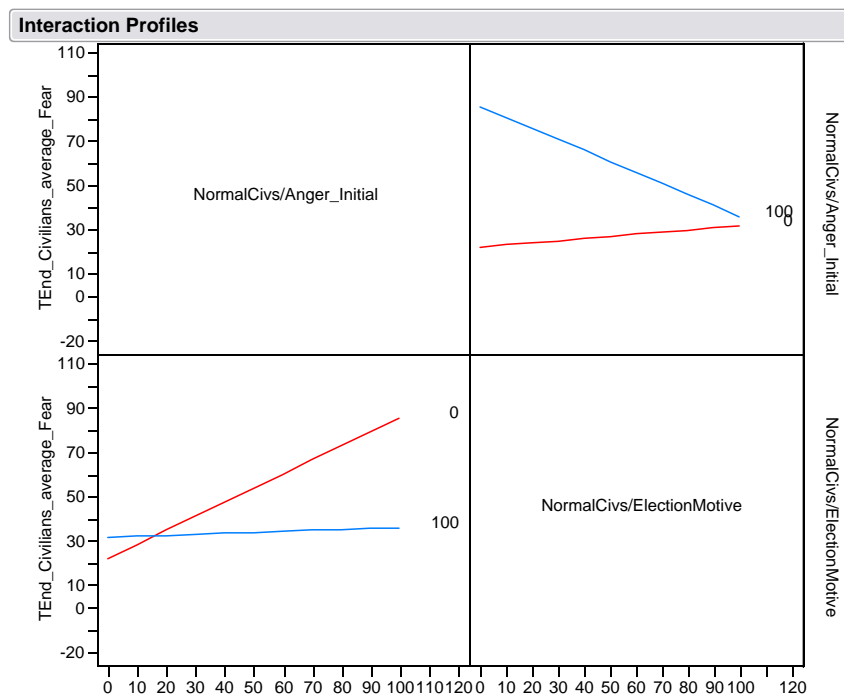


Figure 53 Interaction plots for *TEnd_Civilians_Average_Fear_NoLeader* Model.

5. Investigation of Final Average Civilian Anger

Similar to fear, measuring the average anger among the civilians would give another indication of the wellness of the population. It would be detrimental to future peacekeeping operations if the civilians are left angry, with increased likelihood of more conflicts and violence.

a. Entire Set of Scenarios

When a model was fitted for the combined data set, $R^2 = 0.400$ was achieved with eight main effect terms. Figure 54 shows the slopes and associated p-values. It was observed that only the factors that affect the civilians showed up as statistically significant, with the *NormalCivs/Anger_Initial* and *NormalCivs/Anger_Dynamics* as being the terms with greater slopes. Soldiers' Rulesets did not seem to matter for this MOE.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	80.633188	3.493513	23.08	<.0001
AggressiveCivs/Anger_Initial	0.1640033	0.024206	6.78	<.0001
AggressiveCivs/Anger_Dynamics	-0.124811	0.024205	-5.16	<.0001
AggressiveCivs/Fear_Initial	-0.09826	0.024206	-4.06	<.0001
NormalCivs/Anger_Initial	0.2852036	0.024206	11.78	<.0001
NormalCivs/Anger_Dynamics	-0.314593	0.024206	-13.00	<.0001
NormalCivs/RFA_Initial	-0.153515	0.024205	-6.34	<.0001
NormalCivs/Fear_Initial	-0.159727	0.024206	-6.60	<.0001
NormalCivs/Fear_Dynamics	0.1380916	0.024206	5.70	<.0001

Figure 54 Parameter Estimates for TEnd_Civilians_Anger_Combined_All Model.

The model for TEnd_Civilians_Average_Anger_Combined_All may then be represented by:

$$\hat{anger}(all) = 80.633 + 0.164x_1 - 0.125x_2 - 0.0983x_4 + 0.285y_1 - 0.315y_2 - 0.154y_3 - 0.160y_4 + 0.138y_5$$

where:

$x_1 = \text{AggressiveCivs}/\text{Anger_Initial}$

$x_2 = \text{AggressiveCivs}/\text{Anger_Dynamics}$

$x_4 = \text{AggressiveCivs}/\text{Fear_Initial}$

$y_1 = \text{NormalCivs}/\text{Anger_Initial}$

$y_2 = \text{NormalCivs}/\text{Anger_Dynamics}$

$y_3 = \text{NormalCivs}/\text{RFA_Initial}$

$y_4 = \text{NormalCivs}/\text{Fear_Initial}$

$y_5 = \text{NormalCivs}/\text{Fear_Dynamics}$

b. Civilian Leader Present

Next, a model was fit for the subset data with a civilian leader. An $R^2 = 0.334$ was achieved with seven main effect terms and two interaction terms. Although once again the Soldiers' Rulesets did not matter for this MOE, LeaderCooperativeness showed up as statistically significant.

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	83.071151	5.87964	14.13	<.0001
AggressiveCivs/Anger_Initial	0.1304609	0.030568	4.27	<.0001
AggressiveCivs/Fear_Initial	-0.08667	0.030567	-2.84	0.0048
NormalCivs/Anger_Initial	0.2067617	0.030568	6.76	<.0001
NormalCivs/Anger_Dynamics	-0.285213	0.030568	-9.33	<.0001
NormalCivs/RFA_Initial	-0.169221	0.030567	-5.54	<.0001
NormalCivs/Fear_Initial	-0.11538	0.030568	-3.77	0.0002
LeaderCooperativeness	-0.005678	0.088917	-0.06	0.9491
(NormalCivs/Anger_Initial-50.0155)*(LeaderCooperativeness-50)	0.0179663	0.003057	5.88	<.0001
(NormalCivs/Fear_Initial-50.0155)*(LeaderCooperativeness-50)	-0.012215	0.003057	-4.00	<.0001

Figure 55 Parameter Estimates for TEnd_Civilians_Anger_Leader Model.

The model for TEnd_Civilians_Average_Anger_Leader may then be represented by:

$$\begin{aligned} \hat{anger}(Leader) = & 83.0711 + 0.130x_1 - 0.0867x_4 + 0.207y_1 - 0.285y_2 - 0.169y_3 \\ & -0.115y_4 - 0.00568v_2 + 0.0180(y_1 - 50.0155)(v_2 - 50) \\ & -0.0122(y_4 - 50.0155)(v_2 - 50) \end{aligned}$$

where: $x_1 = AggressiveCivs/Anger_Initial$
 $x_4 = AggressiveCivs/Fear_Initial$
 $y_1 = NormalCivs/Anger_Initial$
 $y_2 = NormalCivs/Anger_Dynamics$
 $y_3 = NormalCivs/RFA_Initial$
 $y_4 = NormalCivs/Fear_Initial$
 $v_2 = LeaderCooperativeness$

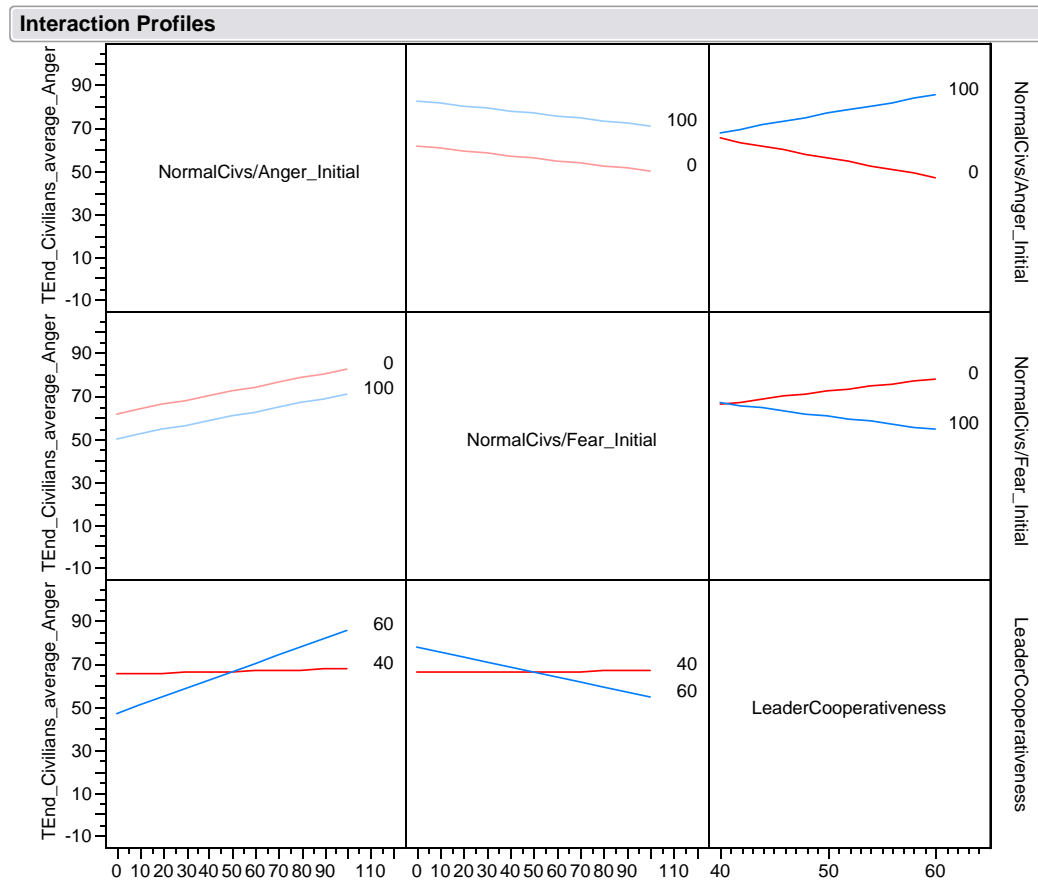


Figure 56 Interaction Plots for TEnd_Civilians_Anger_Leader Model.

From the interaction plots, it was noted that in the presence of a LessCoopLeader (LeaderCooperativeness = 40), the *NormalCivs/Anger_Initial* and *NormalCivs/Fear_Initial* did not have much impact on the TEnd_Civilians_Average_Anger MOE. However, when there is a slightly more cooperative leader, *NormalCivs/Anger_Initial* and *NormalCivs/Fear_Initial* could affect the MOE significantly (by a combined amount up to 50).

c. Civilian Leader Absent

Next, a model was fit for the subset data without the civilian leader, a $R^2 = 0.656$ was achieved with eight main effect terms only. In fact, these were the same 8 terms found when using the combined data set. Though the values of the slopes were different, they agreed in signs. The R^2 in this NoLeader case

is also higher than the previous combined case of 0.400. The Actual by Predicted plot, parameter estimates, and p-values are shown in Figure 57 .

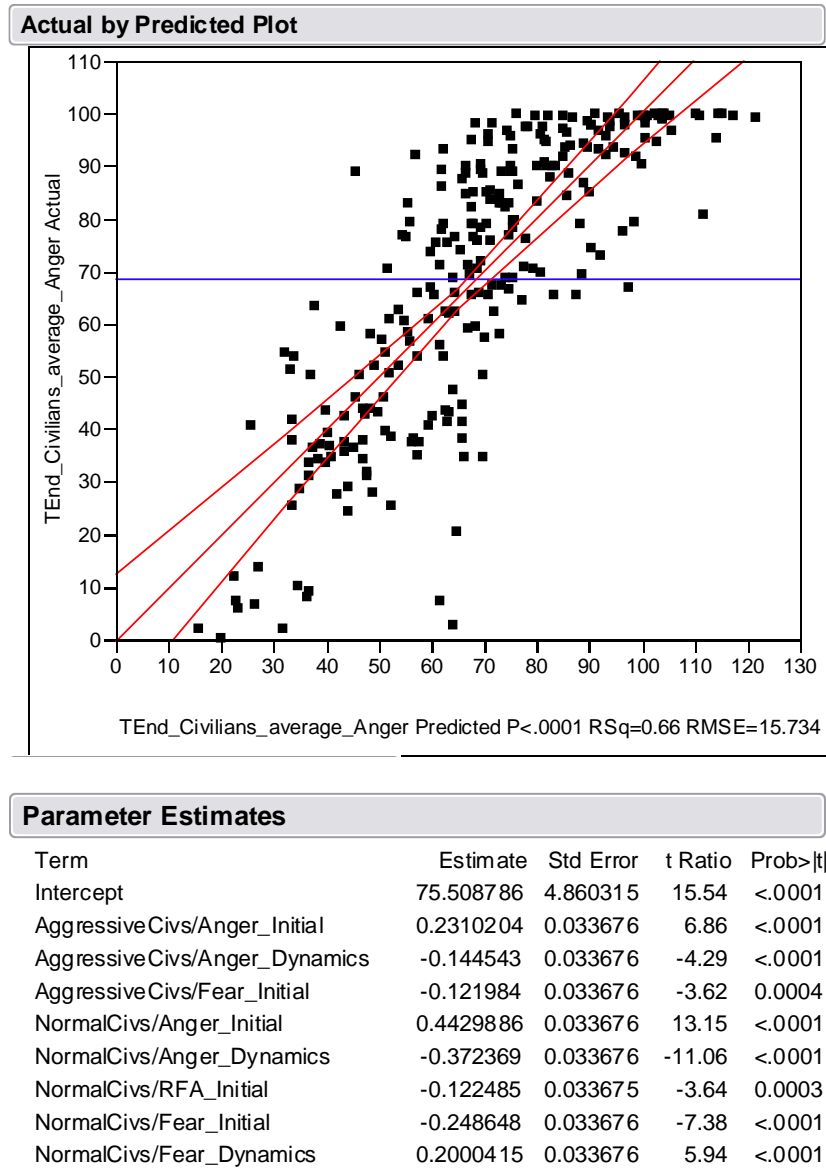


Figure 57 Parameter Estimates for TEnd_Civilians_Anger_NoLeader Model.

The model for TEnd_Civilians_Average_Anger_NoLeader may then be represented by:

$$\hat{anger}(NoLeader) = 75.509 + 0.231x_1 - 0.145x_2 - 0.122x_4 + 0.443y_1 - 0.372y_2 - 0.122y_3 - 0.249y_4 + 0.200y_5$$

where: $x_1 = AggressiveCivs/Anger_Initial$
 $x_2 = AggressiveCivs/Anger_Dynamics$
 $x_4 = AggressiveCivs/Fear_Initial$
 $y_1 = NormalCivs/Anger_Initial$
 $y_2 = NormalCivs/Anger_Dynamics$
 $y_3 = NormalCivs/RFA_Initial$
 $y_4 = NormalCivs/Fear_Initial$
 $y_5 = NormalCivs/Fear_Dynamics$

The two terms *NormalCivs/Anger_Initial* and *NormalCivs/Anger_Dynamics* continued to have dominating effects on the *TEnd_Civilians_Average_Anger*, with combined effects of up to 80 units.

E. SUMMARY OF RESULTS

The four MOEs discussed in previous sections are:

- Aggregated Escalation
- Number of Civilian Who Crossed Checkpoints
- Final Civilian Average Fear
- Final Civilian Average Anger

For each MOE, three models were developed, one called the combined model, which looked at all the data set as a whole, while the other two investigated separately the effects of the 18 factors on the MOE with or without a civilian leader for one of the two civilian groups.

Table 9 gives a summary of the main effects that showed up as contributing factors in the experiments conducted, with reference to the four MOEs only.

	Identifier	Aggregated_Escalation (Combined_all)	Aggregated_Escalation (With_Leader)	Aggregated_Escalation (No_Leader)	Election (Combined_all)	Election (With_Leader)	Election (No_Leader)	Tend_Civilians_Average_Fear (Combined_all)	Tend_Civilians_Average_Fear (With_Leader)	Tend_Civilians_Average_Fear (No_Leader)	Tend_Civilians_Average_Anger (Combined_all)	Tend_Civilians_Average_Anger (With_Leader)	Tend_Civilians_Average_Anger (No_Leader)
	Rsquare	0.3702	0.2304	0.6227	0.3895	0.3303	0.5719	0.3251	0.2276	0.4346	0.4004	0.3336	0.6560
x ₁	AggressiveCivs/Anger_Initial	-	-	-				-	-	-	-	-	-
x ₂	AggressiveCivs/Anger_Dynamics			+							+		+
x ₃	AggressiveCivs/RFA_Initial	-	-	-				-	-	-			
x ₄	AggressiveCivs/Fear_Initial							+	+		+	+	+
x ₅	AggressiveCivs/Fear_Dynamics												
x ₆	AggressiveCivs/NormsForAntiAggression												
x ₇	AggressiveCivs/GroupCohesiveness	-		-		-							
y ₁	NormalCivs/Anger_Initial				-	-	-	-	-	-	-	-	-
y ₂	NormalCivs/Anger_Dynamics				+	+	+					+	
y ₃	NormalCivs/RFA_Initial		-	-				-	-	-	+	+	+
y ₄	NormalCivs/Fear_Initial		+		+		+				+	+	+
y ₅	NormalCivs/Fear_Dynamics				-		-				-		-
y ₆	NormalCivs/NormsForAntiAggression												
y ₇	NormalCivs/GroupCohesiveness												
y ₈	NormalCivs/AngerDecreaseOnSuccess												
y ₉	NormalCivs/ElectionMotive		-		+	+	+	+		+			
z ₁	Reserve/Ruleset{6&1&2&5&3-4}	+		+				-		-			
z ₂	Reserve/Ruleset{6-1&5&2&3&4}		+										
z ₃	Reserve/Ruleset{1&5&2&3-4}		+										
z ₄	Reserve/Ruleset{4&3&6-2&1&5}								+				
z ₅	AdmissionControl/Ruleset{5&3&6&1&4-2}		+										
v ₁	Leader[0]	-											
v ₂	LeaderCooperativeness					+						-	

Table 9 Summary of Model Terms.

A “+” sign indicates that the presence of the term in the model has a positive or good effect, or that it is improving the MOE. A “-” sign indicates that the term has negative impact on the model.

The readers are again reminded that NormalCivs should be viewed as pass-holders that are allowed to go across the checkpoint while AggressiveCivs

represent the non-pass-holders. Due to the range of values used for the experiments, the pass-holders (NormalCivs) could at times be more aggressive than the non-pass-holders (AggressiveCivs). It is noted that some parameters did not appear in any of the models. These include terms such as *AggressiveCivs/Fear_Dynamics*, *AggressiveCivs/NormsForAntiAggression*, *NormalCivs/NormsForAntiAggression*, *NormalCivs/GroupCohesiveness* and *NormalCivs/AngerDecreaseOnSuccess*. It was not conclusive that they were not important, but rather they did not seem to be significant for the specific MOEs that were studied given the ranges of other factors in the experiment.

While some terms (like *Reserve/Ruleset=4* and *NormalCivs/RFA_Initial*) appeared to have mixed impacts on different MOEs, most were either always positive or always negative.

a. Initial Anger

It is rather intuitive that as the initial anger levels of the civilian groups increase, there is a higher likelihood that there will be higher escalation of the situation, resulting in higher average fear and anger at the end of operation. It is therefore important that decision makers assess the situation and understand the impact that a hostile and angry group may have detrimental effects on the success of the operation.

It is noted that the *AggressiveCivs/Anger_Initial* is a significant factor in the Escalation model, but not in the Election model. On the other hand, the *NormalCivs/Anger_Initial* is not critical in the Escalation model, but plays an important role in the other three models. Hence, we see that if the needs of the civilians are overwhelmed by anger, it would distract them from their original intention.

b. Election Motive (Needs)

The positive impact of higher *ElectionMotive* in the Election model is rather obvious. However, it is interesting to note that in the Fear model,

ElectionMotive also has a similar contribution. It was observed that when the civilians who were also eligible pass-holders had a goal or a clear objective such as going to vote or simply going across the checkpoint to the marketplace, they would have a lesser likelihood of engaging in some sort of violence. This in turn led to lower overall fear.

In real life situations, this is probably also the case. If crowds are loitering aimlessly, it increases the risks of unnecessary interactions between groups that could possibly lead to conflicts. For the peacekeeping force, it is therefore important to prevent people loitering around the checkpoints. When crowd starts to form, it is often even harder to disperse them, as crowd dispersion often led to clashes and escalation, resulting in a more fearful population.

c. Reserve Rulesets (Rules of Engagement & Tactics)

In the Escalation model, when the Reserve soldiers are assigned Ruleset 4 (the Gandhi strategy), it led to high escalation of the situation. Through simulation and the animation process, we saw that when the soldiers tried to pacify the civilians, the civilians had a higher tendency to take advantage of the situation and continued to threaten or attack the soldiers. This could lead to further violence. It is also noted that when the Gandhi strategy was used, things might have escalated so high that it would be unrealistic to expect the operation to continue with the soldiers using Gandhi strategy. However, once the Rulesets are assigned to the soldiers, these could not be changed dynamically during the simulation. On the other hand, when effectiveness is measured by having low average fear among the civilians, the Gandhi strategy works well. With the soldier always pacifying the civilians, the average fear at end of operation was kept to a relatively low level.

Therefore, the same tactics applied to any situation may have positive impact on one MOE, while being detrimental to another. On one hand, the decision maker would like to have escalation contained, without having to

resort to more drastic defensive measures in order to calm the public down. There is a need for the decision maker to juggle between these possibly conflicting requirements and determine what trade-offs might be necessary.

d. *Presence of Leader and Leader Cooperativeness*

The R^2 for the models are generally higher in the case of NoLeader for the four MOEs investigated. This could be due to the currently limited implementation of leader, its cooperativeness and possibly due to the fact that there is not means to define the cooperativeness of other non-leader civilians. However, in a dynamic environment, it is highly possible that the cooperativeness of the civilians towards their leader and even towards the soldiers play an important role in determining the outcome of a conflict situation. As such, further research into this area is recommended.

V. CONCLUSIONS AND RECOMMENDATIONS

This thesis demonstrates the use of agent-based simulation in the study of peace support operations, utilizing the prototype PAX software package. From the experiments, models are developed to identify factors that are significant to the outcome of such operations, thus providing insights to decision makers. This chapter contains the conclusions drawn from the analysis of the 18 main factors by looking at four MOEs of interest specifically to peace support operations. At the same time, lessons are learnt from using the PAX software package and doing the analyses, which are also included in the hope of providing the PAX developers some feedback for future enhancement.

A. PEACE SUPPORT OPERATION SCENARIO

MOEs that are used in traditional combat-oriented attrition-based models are not suitable for use when modeling the peace support operations. The four MOEs that are discussed in previous sections in assessing the effectiveness and success of the peace support operations are:

- Aggregated Escalation
- Number of Civilian Who Crossed Checkpoints
- Final Civilian Average Fear
- Final Civilian Average Anger

When planning for peacekeeping operations, such as manning a checkpoint in a martial law scenario, decision-makers need to assess the civilian populations in terms of their anger, fear and anxiety levels. Loitering around the area of the checkpoint should be avoided. When the somewhat aggressive and angry non-pass-holders start to form crowd, group dynamics and interactions with the pass-holders who are going across the checkpoint could lead to conflicts and escalation of the situation.

Peacekeeping forces are more likely to interact with civilians rather than combatants. Hence, the rules of engagement and tactics that soldiers employ will significantly impact the outcome of the operations. The Gandhi strategy (always pacifying the civilians) is good in containing the civilian average fear level but very often result is high escalation when the civilians take advantage of these soldiers' actions. On the other hand, a Zero Tolerance strategy works best in containing the escalation when a civilian leader is present in the non-pass-holder group, although it is likely to leave more civilians fearful at the end of the operation. It is therefore important for the decision-makers to consider trade-offs, depending on the specific situations, the desired outcomes and the short-term or long-term objectives.

B. PAX (DEVELOPERS)

The developers of PAX have taken a bold step by trying to model human behavioral aspects and measuring some abstract quantities such as escalation. Since PAX is still under development and the version released is considered as a prototype, some teething problems are expected. The following feedback to the developers is aimed at improving the software for the benefits of the larger simulation community.

1. Installation & Scenario Setup

Strictly speaking, PAX does not install anything onto the local machine. It comes in a compact zipped file and the user just need to unzip the content to any directory, keeping the directory hierarchy intact. The PAX Scenario Editor is easy to run and the user can easily setup basic scenarios. The graphical user interface is simple and intuitive in most cases, allowing an amateur user to quickly setup scenarios without much trouble.

For exploration purposes, PAX provides a simple but yet meaningful animation process that allows the user to examine the simulated events closely for better understanding.

2. Experiments & Data Collection

PAX also has an Experiment Editor that allows the user to create study files for doing multiple runs, as in the case of data farming scenario. However, the user needs to execute tasks from the command line, which may require some practice. As the procedures are still being refined, it is hoped that future development could fine-tune these procedures to allow larger scale data farming to be carried out more easily.

The post-processing with PAX experiment data is straightforward, although it is also done through command line. However, it is a very simple single step to collate the data in a comma-separated file, which can then be easily imported into any standard statistical analysis software packages.

3. Advanced Features Are Not Easily Accessible

Since PAX is developed with the German Army as the primary customer, its employment is currently confined to within the developers and limited use by the Project Albert participating members.

Special or more advanced features, such as defining the direction of a cell, are hidden in the “Custom Parameters” menu. It presents the users with some difficulties in trying to fully exploit the capabilities of PAX, and there is a need to update the User Manual to allow the user to take advantage of these features. Furthermore, the parameters need to be entered in German. This could be due to the fact that PAX was developed by Germans and, naturally, the first release used German as the language for the graphical user interface. An English version was released only recently, much as a direct translation from the previous German version and hence some of the legacy issues.

4. Modeling Issues

PAX was initially designed to answer questions specific to the food distribution scenario. As the model matured, more features were added to

enable the investigation of an election scenario. PAX developers constantly engaged professionals in social psychology and military advisers to fine-tune the model and compare results against real-life operations to gain experience in improving the fidelity and accuracy of the model and the internal dynamics.

With the aid of animation in PAX, we are able to observe the events or processes that lead to a successful mission, violent interactions or simply a standoff situation. There was an observation during one of the scenario runs that AggressiveCivs got fearful after attacking the NormalCivs, who did not react with any form of retaliation. One possibility is that the NormalCivs were very fearful and the AggressiveCivs were influenced by them, as a result of interacting group dynamics. Such example illustrates the complexity of the situation and the difficulties in modeling human and group behaviors. PAX developers continue to investigate such issues and improve the model and further research efforts will be required.

5. Additional Modeling Capabilities

This thesis has demonstrated the ability to model certain aspects of a checkpoint operation scenario using PAX. There are, however, some limitations that constrained the extent which the scenario could be investigated.

a. Separate MOEs for Civilian Groups

Currently, PAX aggregated some MOEs for all the civilians, such as average fear and average anger. However, the ability to distinguish such measures among civilian groups would be very beneficial. There is a possibility that one group might turn very fearful while another may not, but the aggregated result may show that the average fear is moderate. It would thus mask the real issue and could not really allow a more detailed study of a specific civilian group.

b. Time and Number To Cross Checkpoint

It is also important to be able to record the number of pass-holders that manage to cross the checkpoint, as well as the time required to complete the operation. This would allow the efficiency of different checkpoint configurations to be modeled and evaluated.

c. Patrols

There are currently only two types of soldiers modeled in PAX, namely the Reserve Soldiers (which was first developed for the food distribution scenario) and the Admission Control Soldiers (which was added for the election scenario). These served well in fulfilling the requirements for the previous scenarios. In the checkpoint scenario, the ability to model foot patrols would be useful. This would allow the study of doctrine, tactics and procedures for the employment of such patrols.

One word of caution though, is the need to guard against so-called “model creep”. While the terms “mission creep” or “requirement creep” (referring to the gradual expansion of the mission or need over time) are widely recognized throughout the military, model creep refers to the gradual increase in complexity of a model as a problem is investigated. It is common for an analyst to think that the model is never detailed enough. There will always be some aspect of the universe that is currently not represented and the analyst feels “should” be included in the model. As a result, the model grows. The proper definition of research questions, and the design of an experiment to answer them, helps to prevent model creep. It is always a challenge to know that enough detail is available to provide insight to the questions the decision-makers have, and stop adding unnecessary complexity to the model.

C. DIRECTIONS FOR FUTURE RESEARCH

As the use of modeling and simulation for peace support operations proves viable and benefits become evident, there will be increasing demand for new features to expand the modeling capabilities of PAX or develop new platforms capable of incorporating human behavioral aspects. The advancement in high-performance computing and maturing of agent-based models, coupled with good experimental designs and data-farming techniques, will allow analysts to investigate more peacekeeping operation scenarios, thereby providing insights to the decision-makers.

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